SPACE PROPULSION

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SPACE PROPULSION

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., Monday, March 16, 1959.

The committee met at 10 a.m., in room B–214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. The meeting will please come to order.

This morning, members of the committee, we have five witnesses. The first of our witnesses is the Honorable Dan A. Kimball, former Secretary of the Navy, now president of Aerojet-General Corp., Azusa, Calif., and Washington, D.C.

Secretary Kimball has a statement which, as I understand, will take about 15 minutes.

Then we have these witnesses who have come from all over the country—California, Pennsylvania, Alabama, and New Jersey, and of course they are anxious to complete their testimony and get back to their work.

Therefore, my thought is this morning that we could hear Mr. Kimball to start with and then finish our questions with him reasonably early. We can then get through most of the other witnesses.

Today we have a bill on the Consent Calendar, so we will have to adjourn promptly at noon in order to get over there in time to get this bill through. We need everybody on the floor for that.

So, first, the Honorable Dan A. Kimball. Mr. Kimball, if you will come up, sir. We are happy to have you this morning and know the great record you made for the U.S. Government when you were Secretary. My dealings with you were always most pleasant.

Mr. KIMBALL. Thank you, Mr. Chairman.

The CHAIRMAN. We are happy to have you back with us again.

STATEMENT OF DAN A. KIMBALL, PRESIDENT, AEROJET-GENERAL CORP., ACCOMPANIED BY ROBERT B. YOUNG, VICE PRESIDENT, AND DR. JAMES M. CARTER

Mr. KIMBALL. I appreciate the chance to be heard before your committee this morning. I have with me Mr. Robert Young who is the vice president in charge of our liquid rocket plant in Sacramento and Dr. Carter of our research staff who will answer any questions I can't answer.

The CHAIRMAN. If you want to call them forward, sir, it will be all right.

Mr. KIMBALL. Talking about propulsion systems for space, propulsion has always been one of man's basic interests—from earliest history he has wanted to get from one place to another, and usually to get back. All propulsion up to the present, however, has been in

a way tied to the earth, whether a man was sailing the seas, walking or piloting a supersonic plane.

The job of getting away from the earth is a much more complicated one, especially if a return is also wanted. In the first place it means reliance entirely on jet and rocket propulsion—there is nothing to push against. Modern interest in these propulsion systems has revived only in the last 20 years or so, although crude rocket systems have been known for 2,000 years.

This modern revival of rocket propulsion has been accelerating steadily, and now includes not only the conventional (chemical) rocket propulsion systems, but applications involving nuclear power, and electrically charged particles. The evolution of these propulsion systems and their application to the problems of space travel is one of the most exciting features of contemporary history.

The fact that we can recognize many of the problems of space flight, and can plan development programs well into the future with a great degree of assurance, is due to the support which the military has furnished the rocket industry during the past 10 years.

Demonstrated military needs for jet and rocket planes and for ballistic missiles, with their extreme requirements for new propulsion systems with accompanying guidance and communication capabilities led to the evolution of a great body of know-how and of production capability in American industry. Without the results and knowledge generated by this military support, the task of achieving space travel would be almost impossible.

Aerojet-General Corp. is engaged in an across-the-board program on all types of propulsion systems, and I want to tell you what we think the problems are, and what should be done to overcome them.

First, I want to point out, as a basis for later remarks, that there are two fairly distinct aspects to space travel. The earth has a gravitational field and an atmosphere. The first step in getting into space is to get outside the atmosphere, and to neutralize gravitation. At 100 miles we are practically out of the atmosphere, and a horizontal speed of about 5 miles a second will counterbalance the earth's gravity. Once a vehicle has reached this state, which amounts to being in orbit, it is possible to go beyond, and consider actual space travel.

The importance of distinction between reaching orbital conditions and going beyond them lies in the great difference in propulsion requirements. To overcome earth's gravity, a large specific thrust (thrust-weight ratio) is required. At present, the only means we have for doing this is by chemical (solid or liquid) rockets. (There is some possibility that nuclear rockets can be developed for this purpose, if the problems of heat transfer, shielding, and extremely high temperatures can be solved.) This means that improvement in solid and liquid chemical rockets will be required over many years, to increase performance and reliability and to decrease costs.

Once a vehicle has reached orbital conditions, propulsion requirements to send it beyond, to the moon, to other planets, or to travel through space, are much less stringent, since the requirement for high specific thrust is removed. It is a characteristic of the advanced electrical propulsion systems that while their performance (specific impulse) is high, their specific thrusts are low, because of the weight of the powerplant required. While chemical and possibly nuclear rock-

ets can have a specific thrust well above 1, electrical propulsion systems have specific thrusts ranging from one one-hundredth to one-millionth.

In listing specific problems for the next 10 years or so, I will begin with the more conventional propulsion systems and then go on to the exotic ones. There is actually little essential difference between solid and liquid rocket systems in that they both employ the same type of combustible propellants and function in the same way.

The propellants burn, are converted to gas, and are accelerated through a nozzle to produce thrust. It is obvious they will both be used for the foreseeable future to escape from the earth, and also for any rapid changes in direction or velocity in space.

Possibly the major problem with both is development of larger sizes. We now have engines in the 200,000-pound thrust class. The Russians apparently have somewhat larger ones. We are developing engines in the million-pound class, and we can at least think of engines with a thrust of 5–10 million pounds as being required to put a space station, or components for a space station, in orbit. There is obviously a practical upper limit to the size of propulsion systems. We need to find out what it is.

As you doubtless know, all of our satellites and other space vehicles comprise a number of stages of successively smaller size. Again in this case, the largest and most expensive is the first or boost stage to get the vehicle started.

In terms of size, weight, cost, and criticality, it exceeds all the other stages put together. We have made a number of studies at Aerojet, which indicate that our most pressing problem is that of reducing the weight, complexity, and cost of large first-stage or booster engines.

The problems for solid and for liquids are sufficiently distinct with respect to the above that they are considered separately. We now have solid rocket engines with a thrust of 200,000 pounds, using propellants with a specific impulse of 250 seconds. Increase in size to the order of a million pounds involves structural problems in the propellant itself, as well as problems with the pressure case.

Improvement in performance which will come will involve the combined efforts of the chemical industry to provide new fuels and oxidizers, of the propellant manufacturers to develop means of preparing usable propellants, and of the engine fabricators to develop means of resisting high tempartures, corrosion, and operating loads.

In the liquid field, we have at present propellants of as high performance as it is likely we shall ever obtain. These have been tested on a small scale, but require further development to render them operational on a large scale.

A more important problem is that of improving reliability and decreasing cost. In talking of a vehicle of 1 million pounds takeoff weight we must consider that this will represent about 500,000 pounds of propellant in the first stage and about 50,000 pounds of hardware (engine, pumps, valves, piping, structure, and tanks).

Liquid propellants are cheaper than solid propellants, but hardware, even after development, is much more expensive, and with present designs, it does not appear hardware costs can be greatly reduced. There are three methods of cutting these costs, all of which are being actively investigated at Aerojet.

The first is to decrease the hardware weight. If we could cut the hardware weight by a factor of 2 in the example above, we could save a great deal of money a shot. The second is to adopt some simpler and less sophisticated designs for first-stage engines which could make it possible to go to "regular production" methods of manufacture, and cut hardware costs by a factor of three, without any great increase in weight.

This, again, would save about the same money per shot. The third method is to develop a recoverable first stage which could be used a number of times over. While such a recoverable stage might cost half again as much per pound, if it could be used for a half-dozen or more times, it would save a major part of the cost.

For the second and following stages, the problems are somewhat different. In the first place, since the following stages make up a part of the payload of the first stage, their performance must be as high as possible to decrease their weight. This involves use of the best propellants we know—liquid hydrogen and liquid oxygen or liquid fluorine.

It seems highly improbable that any better propellants, will be available for many years. (The development of free-radical propellants, on which Aerojet is working, is a long-range program, and indeed may never produce usable propellants.)

There is an immediate need for a comprehensive program to develop operational capability, with a high degree of reliability, in propulsion systems using liquid hydrogen and liquid oxygen or liquid fluorine. The thrust range required for these systems is from 300,000 pounds down to about one-tenth as much.

For rapid propulsion in space, after orbital conditions have been reached, the requirements are similar for high performance, but in addition, the propellants used must be capable of being stored in space for periods of from several days to a year or more. Liquid hydrogen must be kept at a temperature about 400° Fahrenheit below zero; liquid oxygen and liquid fluorine require temperatures almost as low. We do not know what is required to maintain these temperatures in space. If it proves impossible or too difficult, we must back up and use the best propellants we can maintain in space. The problems of achieving operational capability and high reliability are the same.

When we leave the chemical propulsion systems for nuclear and electrical systems we are going largely into unmapped territory. Some of the principal problems can now be recognized, but any program for utilization must necessarily be long range; specific problems remain to be recognized.

The principal area of interest in nuclear rockets at present is in simply using a conventional nuclear reactor, instead of a chemical reaction, to heat the rocket gases. If hydrogen is used as the working fluid it is possible to approximately double the performance of chemical rockets.

Other substances, such as ammonia, give little or no improvement over chemical systems. This propulsion system can provide a high thrust-weight ratio, but involves serious problems in heat transfer, high temperature materials, radiation hazard if used for takeoff, and shielding, especially for manned flight. An advantage is the pos-

sibility of achieving single stage operation, and the possibility of using the reactor for other power needs, such as communication and maintenance of environment in manned vehicles.

An indication of the problems involved is shown by the fact that to get worthwhile propulsion, it is necessary to operate the nuclear reactor at temperatures of 4,500 degrees Fahrenheit or higher. Also, generation of a million pounds of thrust requires a heat transfer of some 25 million B.t.u. per second, or the equivalent of a large central station powerplant occupying a city block.

Beyond the nuclear heating propulsion system are the various electrical systems, which are also based on nuclear energy. In addition to a reactor, they require equipment to generate electrical power, and radiators to dispose of the heat not converted to power. These advanced propulsion systems are urgently needed for long-range space missions such as manned probes to Mars or Venus and beyond, since they offer the only presently known means of accomplishing such missions without the expenditure of truly astronomical amounts of propellants.

In addition to to the requirements for the lightweight reactors and efficient electrical generators common to all of this new generation of propulsion systems, there are specific problems in each system. These are extremely varied, since these advanced concepts include the use of ions, charged colloid-size particles, plasma jets, and magneto-hydrodynamic devices.

As an example, the use of an ion system to generate only 1 pound of thrust requires producing an ion beam of two amperes at some 20,000 volts. The ion beams which have been studied up to the present are a few milliamperes at most, so a scale-up on the order of a thousand or more is needed.

The scientific principles associated with these electrical propulsion systems have been established in the laboratory. Efforts to date in this field have been supported primarily by Government research organizations; consequently the funding has been relatively small.

We believe that the state of the art is such that reduction to practice through a technical development program to demonstrate the feasibility of an integrated electrical propulsion system should be initiated immediately. We at Aerojet think that a program to develop a flyable electrical propulsion system within the next 5 years will have reasonable opportunity for success. It is now time for much larger effort to develop the electrical propulsion systems for space application.

You may ask what all these complex and admittedly costly developments will do for this country. A simple answer would be to say they will give us capability in space. An answer with more meaning would give reasons for wanting capability in space.

There are three areas which may be concerned, and I can give you a few thoughts on each, in what is probably the inverse order of their importance: First, there is the area of military application, frankly, we do not know what the military applications of space are, especially as we proceed farther and farther away from Earth. Equally importantly, we cannot say there are no military applications until we find out, and our national survival in the face of Communist policy requires that we do find out.

The second area is that of what can be termed propaganda and prestige. The Russians are ahead of us in several fields of solid scientific achievement. We do not object to being left cold in some ways, such as establishing slave labor camps, but we cannot afford to have world opinion regard the Communist system as being more capable in worthwhile activities.

The third, and undoubtedly most important area, is that of the extension of human knowledge and activity. For the first time the possibility is arising for man to take a look at himself, his planet, and the universe from points away from the earth's surface. As Dr. Teller recently stated, the only sure advantage from getting into space is an increase of knowledge. But almost as surely, an increase in knowledge will lead to more tangible advantages in the future.

The IGY work of 1958 seems to me to correspond very closely to Columbus' discovery of the new world in 1492. At that time there followed a period of exploration that had a profound effect on almost every aspect of life. I think that in the next decade the preliminary explorations we will make in space will affect the life of everybody on earth.

I think it will serve to improve weather forecasting, to provide storm warnings and might increase our knowledge of weather and climate phenomena and can certainly be used as relays for communications purposes.

I would like to leave you gentlemen with a story which I am sure will be of interest to you as legislators. Something over 100 years ago, a Member of Parliament visited Sir Michael Farady in his laboratory, where he was conducting some of the first experiments in a new field—electricity.

The Member of Parliament was interested, but asked, "What use is it?" and Faraday replied, "My dear sir, someday you may be able to tax it."

I am sure if you gentlemen will look at the hundreds of millions of dollars in taxes paid in this country alone by the electric power and equipment industries, you will agree that the pursuit of knowledge can be extremely rewarding.

The next two pages I won't read, but we have there what we believe are the requirements for solid engines, for liquid engines, nuclear engines, and electrical propulsion systems that should be pursued in the immediate future.

(This additional material is as follows:)

REQUIREMENTS FOR PROPULSION SYSTEMS DEVELOPMENT

I. SOLID ENGINES

A. First stage or boost:
   1. Investigation problems of size increase to 500,000–1 million pounds thrust, and 500 million pound-seconds total impulse.
   2. Improve flexibility of operation.
   3. Cut cost of finished propellant in place in engine, that is, continuous mixing, increased use of chemical industry methods.
   4. Improve preformance.

B. Following stakes or space:
   1. Improve performance.
   2. Improve flexibility.
   3. Demonstrate storability in space.

II. LIQUID ENGINES

A. First stage or boost:
1. Improve reliability—use present propellants.
2. Decrease hardware cost and complexity.
(*a*) Increase propellant fraction.
(*b*) Decrease storage and pumping problems.
(*c*) Investigate recoverable units.
(*d*) Investigate inexpensive hardware, that is, mild steel, plastics.

B. Following stages or space:
1. Increase performance—very best propellants.
2. Improve reliability.
3. For space—demonstrate storage under space conditions: Are cryogenics usable?

III. NUCLEAR ENGINES (RESTRICTED TO NUCLEAR HEATING OF WORKING FLUID)

A. First stage or boost: 1. Investigate practical feasibility versus chemical—radiation hazard, minimum size, practicality of required heat transfer and high-temperature reactors.

B. Following stages or space:
1. Demonstrate storability of liquid H_2 in space.
2. Investigate integration of propulsion and auxiliary power systems.

IV. ELECTRICAL PROPULSION SYSTEMS (CONFINED TO SPACE)

A. Develop lightweight reactors.
B. Develop efficient converters to electrical power.
C. Ion propulsion systems.
1. Develop efficient, long-life ion sources.
2. Investigate problems of obtaining directed ion beam, electrical neutrality, etc.
3. Investigate problem of reducing specific impulses to usable values.
D. Charged particle propulsion systems.
1. Continue development of liquid droplet systems.
2. Develop methods to employ solid particles.
E. Other electrical systems. 1. Plasma, magneto-hydrodynamics, and so forth. Investigate.

Mr. KIMBALL. That is all I have, Mr. Chairman.

The CHAIRMAN. Thank you very much, sir, for a very fine statement. I think, of course, you are beginning to get us into trouble when you refer to the possibility of taxing space developments. That will give Congress something to think about right away.

Have you any further recommendations, other than those that you place in your statement, as to what we need to do to advance this program?

Mr. KIMBALL. I think the requirements that I have laid out here in these last three pages cover pretty well the things that should be done.

The CHAIRMAN. You refer to solid engines, liquid engines——

Mr. KIMBALL. I might go over them. We have on solid engines, in the first stage, a booster stage, investigate problems of size increase to 500,000–1,000,000 pounds thrust and 500,000,000 pound-seconds total impulse. Improve flexibility of the operation. Cut the cost of finished propellant in place in the engine by continuous mixing, increased use of chemical industry methods. Improve the performance.

In the following stages, to improve the performance and flexibility, and demonstrate storability in space.

In the liquid engines almost the same thing. Improve the reliability with present propellants. To cut the hardware cost. To increase the propellant fraction. To decrease the storage and pumping

problems. To investigate recoverable units. To investigate inexpensive hardware such as mild steel and plastics.

In the following stages, much the same. Increase the performance with better propellants. Improve the reliability. For space, to demonstrate storage under space conditions.

With the nuclear engine, we think we should investigate the practical feasibility versus chemical-radiation hazard minimum size, practicality of required heat transfer and high-temperature reactors.

In the upper stages, to demonstrate storability of liquid hydrogen in space; to investigate integration of propulsion and auxiliary power systems.

The electrical propulsion systems which would be confined to space—those, I think, are fairly complete. If we try to do all of them, we have got a big job ahead of us.

The CHAIRMAN. We will study that. Do you see any possibility in the near future of reducing the cost of solid fuel propellants?

Mr. KIMBALL. Yes, I think we have to find ways to mix them more efficiently and mix them with the continuous mix processes, rather than with a batch mix, as we do at the present time.

The CHAIRMAN. The cost is one of the prime impediments to the use of solid propellants, isn't it?

Mr. KIMBALL. I don't believe you will get overall much difference in cost between your solids and liquids. Your liquid chemicals cost less than the chemicals you use in the solids, but the complexity of the hardware, the metal parts, is much more.

So they will balance off reasonably well.

The CHAIRMAN. I think somebody testified here that the cost of the solid propellants would run from $3 to $5 a pound. Do the liquids run in that same proportion?

Mr. KIMBALL. The $3 to $5 per pound would be the overall cost. The propellants themselves don't cost that much. They cost you from 40 cents to a couple of dollars a pound in the raw state, but you get the $3 to $5 by the time you have to mix them and put them together and test them.

Have you any thoughts on that, Mr. Young?

The CHAIRMAN. And your name, sir, for the record?

Mr. YOUNG. I am Robert B. Young, vice president of the liquid rocket plant at Sacramento. I am speaking for our liquid propellent activity.

Liquid propellants are cheap in the bulk. As you all know, hydrogen and kerosene run just a few cents a pound; but the equipment that is required to operate the engines is rather complex and runs currently, say, $100 a pound.

So if you take an all-out missile system—which you are interested in—your launching, there isn't too much difference right now. We are looking forward to decreasing the cost of the solid propellent systems by—as Mr. Kimball mentioned—continuous propellent mix and perhaps using larger quantities and getting lower cost per unit.

At the same time we are looking forward to decreasing the present high cost of the liquid engines by simplifying them, using different methods of operation which lead to simpler engines.

The CHAIRMAN. Which will promote the efficiency?

Mr. YOUNG. Promote the efficiency, reduce the cost, and increase the reliability. Possibly, current large liquid engines have been tagged as being unreliable, although in practice they are doing pretty well. I am speaking of our ICBM engines, which represent the furthest advance of the art in this country.

But we are looking forward to significantly increasing the reliability, decreasing complexity, and increasing the output of such engines as well as engines of larger thrust—again using either the present propellants or different propellants, depending upon the applications.

The CHAIRMAN. Mr. Fulton.

Mr. FULTON. I certainly want to welcome you, Mr. Kimball. You have a very interesting idea when you speak of taxes in space. That would, of course, mean private property in space, or the Government couldn't tax you.

Do you mean that in space we should then be able to buy a piece of the Moon or a piece of Mars or we should have a system set up under private enterprise where you might have a transportation system back and forth between the Moon, or once around the world, or should the Government do all of that?

Mr. KIMBALL. It seems to me this is going to be obviously a little too expensive for any private companies to do. This isn't directly related to propulsion, but it seems to me within the next 50 years we are going to have to evolve some space laws. I don't think it is possible to put those down on paper now. You couldn't evolve the laws of the seas; you have got certain precedents; you have got freedom of the seas.

I think you are going to have to have freedom of space within certain limits as you have freedom of the seas. I don't think there is a country that is going to be able to lay a claim to the moon and be able to sustain it.

Mr. FULTON. That is a lot closer, I think, than perhaps you are thinking, because with a telegraphic satellite, with two of those up, we could probably handle all the telegraphic communications of one hemisphere within a year.

That brings up the question: Should that be a private enterprise or should the Government or the United Nations do it?

Mr. KIMBALL. I would think it has to be Government.

Mr. FULTON. You wouldn't let any large company, then, have that satellite, although it only costs $100 million or $200 million, and would cost no more than the same cable facilities?

Mr. KIMBALL. I don't think I am competent to answer that.

Mr. FULTON. You made a point and said we were going to tax all of this.

Mr. KIMBALL. I wasn't suggesting that we tax it, Mr. Fulton. I was just quoting Sir Michael Faraday 100 years ago when he was talking about electricity at the start of it.

Mr. FULTON. So you wouldn't have private industry in space, then?

Mr. KIMBALL. I don't think you could have it; no, sir.

Mr. FULTON. Would you have a limit, then, in our Government on who would be allowed to shoot anything into space? Would you make us, say, get a license or a passport to get into space?

Mr. KIMBALL. No. I think if it is going to be a Government operation, it has to be run as a Government operation.

Mr. FULTON. Then you would prevent any individual or company from going into space without specific authorization?

Mr. KIMBALL. I don't believe you would prohibit them, but I think the cost of doing it would rule them out.

Mr. FULTON. I have just this short line of questions. There has been talk here of coming up with a whole new system of a new hydrogen propellant. As a matter of fact, we have several hydrogen propellants that are hydrogen productive in volume, one about 70 percent in volume and another about 24 percent in volume.

Do you think it is a wise thing to start into a whole new type of propellant production, or do you think it would be wise to develop the ones we have and maybe make them 15, 20, or 50 percent more efficient?

Mr. KIMBALL. I think certainly the best thing we could do would be to develop what we have and make them more reliable and get the cost down.

Mr. FULTON. Then another thing——

Mr. KIMBALL. I think within the next 10 years we are going to use the chemical rockets we are now manufacturing and improve those. I think obviously the things that we have now are what we are going to use to get into space.

Mr. FULTON. Do you think we are moving fast enough on nuclear power in space? There is such a tremendous ratio there that a nuclear power facility will be so light, probably, compared to what we are using now, and be so small and easy to handle. It could probably be used again if it is tightly contained.

Mr. KIMBALL. I don't think we are moving as fast in nuclear power for space as we can and should.

Mr. FULTON. I agree with you. Suppose we did have a program that was set up on a rush basis, as we did once for the rubber industry. I have suggested a man named Admiral Rickover.

Do you think he could put a push on it? To me it needs somebody just to give it a real push and shove it clear ahead.

Mr. KIMBALL. There is no question whether Admiral Rickover would put considerable push on any program that he was working on. He is very efficient. I think somebody has got to make the decision to start the program with a larger dollar effort than is presently being used.

Mr. FULTON. Then if we get a communications satellite up, or the Russians do, within a year, that would give us the power to jam radio communications wherever the satellite was. If you had several of them up, it would give the Nation that had that power of jamming, the power to destroy every radio communication, even military stations, and even the walkie-talkies, or anything on a ship.

That would seem to me to give us quite an urgency then for putting up a communications satellite. In reverse, if you had a very narrow radio band and restricted it so that the satellite was passing over the receiving people, it would not be able to be jammed unless you were within line of sight.

So there might be a danger, mightn't there, if we don't go fast on developing communications satellites that Russia might be able to jam

us out of all radio communications, both civilian and military, and have the ability to withstand jamming by us because of this line of sight communication?

Do you agree with that?

Mr. KIMBALL. Yes, Mr. Fulton, I do. I think when we get satellites in orbit we are going to learn many things about them that we don't even imagine now.

Mr. FULTON. Do you think there is a necessity on communications satellites to go ahead and go quickly?

Mr. KIMBALL. Yes, sir.

Mr. FULTON. Thank you, that is all.

The CHAIRMAN. Mr. Miller.

Mr. MILLER. No questions.

The CHAIRMAN. Mr. Teague.

Mr. TEAGUE. Mr. Kimball, I appreciate the little story, and if we pay for this space aid, we are going to have to find something new to tax.

Mr. Kimball, last week I had lunch with a young scientist from California who believes that there is much duplication going on in all our missile work, that we have scientific teams all over the country doing the same thing.

Would you care to comment on that?

Mr. KIMBALL. I don't think there is any great duplication. I think in most programs you will have a backup, but I don't think there is any great duplication that I have seen.

Mr. TEAGUE. He also contends that there has been contract after contract given to scientific teams that have produced nothing; that actually our people know who those teams are and know they aren't going to produce anything, but they continue to get contracts.

Would you care to comment on that?

Dr. KIMBALL. Yes; I would like to comment on that. I think when you give a research contract to a private firm or university, you are going to make an effort to break through in new fields and you can't be assured that they are going to make a sensational new discovery every time you give a development contract.

Sometimes you get results by getting negative results to find out things you can't do. Certainly when you give a contract to a company or a university to explore some avenue that so one has ever touched, you can't be assured that you are going to achieve a new piece of hardware that you can use successfully.

You can't invent by schedule or by dollars.

Mr. TEAGUE. I notice you said in your statement that your company might not succeed. I am sure your statement is true, but surely there is some way we can evaluate scientific teams to find out whether they are going——

Mr. KIMBALL. I think the military over a period of years has found out the places where they can get work done satisfactorily with a high degree of talent and capability. In our field we try to stay generally in the propulsion field. We think we have fairly competent people.

We have 4,200 technical people, so that when we say we are going to work on a job, we tell them the technical people who are going to work on it and their background and achievements in the past.

Mr. Young here has had 17 years in the liquid rocket business. I would think he is a considerable authority in this country on liquid rockets.

Mr. TEAGUE. Mr. Chairman, that is all I have.

The CHAIRMAN. Mr. Riehlman.

Mr. RIEHLMAN. Mr. Kimball, I have been very much interested in your statement. For my own edification and possibily that of the committee, too, what work are you doing at the present time for the Government?

Mr. KIMBALL. For the Government?

Mr. RIEHLMAN. Yes; in this jet propulsion work.

Mr. KIMBALL. Practically all of the work we are doing at Aerojet-General is for the Government.

Mr. RIEHLMAN. Practically all of your work?

Mr. KIMBALL. Yes.

Mr. RIEHLMAN. And you are working with ARPA and with NASA both?

Mr. KIMBALL. Yes.

Mr. RIEHLMAN. They have free flow of information as to what your scientists have and the new discoveries and the advance in this jet propelled program?

Mr. KIMBALL. They will ask us what we are doing in different fields. We will come back and make a full presentation disclosure to them. They come out to our plant also to see what we are doing.

That is true of ARPA and NASA, the President's Committee—Dr. Killian's Committee, and all the people in universities. As a matter of fact, one of our outputs is the number of visitors we have, something over 20,000 last year.

Mr. RIEHLMAN. I am following up in my own thinking what my colleague from Texas had to say in his questioning as to the fact that we are all interested in this great field and we are doing everything, we hope, we can to advance it.

The fear I have is that we are going to have a lot of duplication and overlapping, and that we are not going to have the free flow of information that is necessary to coordinate these activities and save a lot of money.

Mr. KIMBALL. I think there is a great deal of information for the people who have a need to know it. Obviously most of the things we are working on are classified, and they have to get clearance to come out; but they know the capability of our organization and of other organizations in like work.

I don't think there is too much duplication. I would think that maybe you would need a little broadening of the base in some places.

Mr. RIEHLMAN. We want to do everything that we can constructively and economically to accomplish this effort.

In respect to the advance that we are making in nuclear propulsion, I think you said in answer to a question of Mr. Fulton that you didn't think we were doing enough in that field.

Mr. KIMBALL. That's right.

Mr. RIEHLMAN. Mr. Chairman, I am not so sure that we have had complete information in respect to how far we have advanced. Are we going to have information before our committee as to the program in the field of nuclear propulsion?

The CHAIRMAN. We have a solid week set for that purpose. I think we will cover every feature of it. At the end of the week, if we haven't, we will be glad to have your ideas.

Mr. RIEHLMAN. Fine. I don't have any other questions at this time.

The CHAIRMAN. Mr. Anfuso.

Mr. ANFUSO. Mr. Kimball, you said whatever you are doing now, you are doing under contract for the Government. Is that correct?

Mr. KIMBALL. Yes.

Mr. ANFUSO. Is private capital also invested in your work?

Mr. KIMBALL. Yes, sir.

Mr. ANFUSO. What is the percentage?

Mr. KIMBALL. Let me put it this way. Our company started by doing work that had been done at Caltech during the war years. At the end of the war the services asked us to continue in the rocket business. We are owned 88 percent by the General Tire Co.

So we said we would keep the company going and we would invest our money in it. What we have done for the last 13 years is put back into the business all the profit we have made. We paid our stockholders no dividends.

As rocket propulsion came into prominence for ballistic missiles and now lately for space, our business has expanded. We have got something in the neighborhood of $40 or $50 million invested in it—our own money; and the Government has got, I guess, a little more than that invested.

Mr. ANFUSO. You say that——

Mr. KIMBALL. I will be happy to send you the complete figures, but I think they are classified; so I would have to send them to you.

Mr. ANFUSO. Would you, please.

Mr. KIMBALL. I will be happy to.

Mr. ANFUSO. You say your company has paid no dividends. You mean Aerojet?

Mr. KIMBALL. Aerojet. We haven't been able to. All the money we made we have had to put back into facilities to do these jobs.

Mr. ANFUSO. How do you account for that stock jumping 60 percent or more in 30 days or thereabouts?

Mr. KIMBALL. I sold mine too quick. I can't account for that.

Mr. ANFUSO. Mr. Kimball, are you making any experiments to develop a recoverable first-stage rocket?

Mr. KIMBALL. We are doing a lot of thinking about it. We haven't run any experiments on it. Practically it looks as if we should be able to do it, either bring it back by parachute or possibly put wings on it, where it could glide down.

Mr. ANFUSO. Just now it is in the drawing stage, but not in the experimental stage?

Mr. KIMBALL. That's right. We would hope to do some experiments on that before the end of this year.

Mr. ANFUSO. What do you mean by this statement in your prepared statement on page 3:

> There is obviously a practical upper limit to the size of propulsion systems. We need to find out what it is.

Will you elaborate on that a little bit, please?

Mr. KIMBALL. Maybe there isn't a practical upper limit, but we think some place along the line these engines could be too large to be transported or usable. I might also say 10 years ago we thought that it would be very difficult to make a 200,000-pound engine. Now we know we can make it. There is work going on in this country to develop a 1 million pound thrust engine.

We don't know whether that would be the optimum size, whether you should bundle those together for a first-stage or larger, whether you should make engines 5 to 10 million.

I think some place along the line we have got to try those larger sizes and find out.

Mr. ANFUSO. Would a nuclear rocket be much smaller? It would be, wouldn't it?

Mr. KIMBALL. I think a nuclear rocket would be larger.

Mr. ANFUSO. Would be larger?

Mr. KIMBALL. And of course to use a nuclear rocket, I am not a nuclear expert, but for the first stage, you have some shielding problems and radiation hazards that might be quite severe.

Mr. ANFUSO. Is it possible, however, that a nuclear rocket could produce a one-stage rocket where you wouldn't need all the other stages?

Mr. KIMBALL. Yes, I think that is possible. It would be a long-range development program. I think the practical thing to do is to use the chemical rockets we are now making for the next 5 to 10 years because you have those in being and you have paid the builder to have them developed.

Mr. ANFUSO. So that nuclear rockets are promising if for nothing else than for that particular phase of it, that you might be able to produce a one-stage rocket?

Mr. KIMBALL. We really believe—I would like to have Dr. Carter or Mr. Young correct me if I am wrong on it—that the most promising use for the nuclear rockets would be the upper stages, because you have booster stages now that you can use.

But you can get up in the air with what we have now and the nuclear rocket would show more promise for the upper stage work rather than for the primary booster.

Mr. ANFUSO. Mr. Kimball, if it were possible to get up into the atmosphere and above the atmosphere—that is 100 miles into outer space—a large vehicle or satellite moving slowly and rising all the time which would not require a large thrust—I started my question with the word "if." I don't mean "if." I am not a scientist, but is it possible to envision a rising balloon, a rising large vehicle into the atmosphere which would not require such a tremendous thrust? In other words, is it possible to get up into the atmoshpere one of these space satellites for television and broadcasting and all that which would be extremely heavy, which is strictly for peaceful purposes?

Mr. KIMBALL. I don't think you can move slowly in upper space.

Mr. ANFUSO. I mean which would steadily increase, though, would move slowly into the atmosphere, but then increase its speeds as it entered outer space. Is it possible to envision such a thing?

Mr. KIMBALL. I don't believe so. Would you say so, Dr. Carter?

Dr. CARTER. No, I don't think that is possible. Once you have gotten into orbit or almost into an orbit, it is possible to increase the

velocity very slowly over a period of time. But there is required this 5 miles a second or nearly that to make the thing stable so it doesn't tend to fall back to the earth.

Mr. ANFUSO. Are you also saying that, in order to get a large vehicle through the atmosphere, you must have a very powerful thrust?

Mr. KIMBALL. That's right.

Dr. CARTER. That's right.

Mr. ANFUSO. Mr. Kimball, if we were able to develop a thrust of 5 to 10 million pounds, we could put into the atmosphere satellites, missiles, or vehicles which would make almost obsolete any modern weapons of war. Isn't that true?

Mr. KIMBALL. I couldn't say that, sir. I think before you do that, we have got to find out what we can do with these satellites when we get them up there. I am not sure the satellites are going to make weapons of war obsolete.

Mr. ANFUSO. If you had a thrust of that magnitude, then surely you are going to magnify the war weapons, the missiles, aren't you?

Mr. KIMBALL. You are not going to put the weapons into orbit at the present time. Our intercontinental ballistic missiles already have ranges of about 5,000 to 8,000 miles. That is sufficient for anything we need in the foreseeable future.

It would be possible to put nuclear weapons into orbit and bring them back at a time and place of your choosing; but that is going to be a long-range, hard job.

Mr. ANFUSO. If you could do that, you would have supremacy in outer space?

Mr. KIMBALL. That's right. That is one of the reasons I think we have to work very vigorously in space.

Mr. ANFUSO. That, in and of itself, would be a deterrent to any country if we had such a power?

Mr. KIMBALL. Yes, sir.

Mr. ANFUSO. So I must agree with the other gentlemen on the committee here, that that would be almost a paramount task, paramount function, of all groups in America, to try to get this thrust as soon as possible.

Mr. KIMBALL. I don't think we can overemphasize the importance of this country having a lead in progress in space because we don't know what all the solutions are going to be. Certainly we can't run second place in this one very long. It is too important to our country, in my opinion.

Mr. ANFUSO. In doing this kind of work, in trying to get 1.5-million-pound thrust, or even above that, are you cooperating with other agencies, private or public? Are you sharing knowledge in that field?

Mr. KIMBALL. Yes, sir, because really the reason that we have a capability in space now is because the military over the past 10 years have put lots of money into developing these weapons. So that is why you have vehicles that you can use in space now. If the military hadn't put this money in over the last 10 years we would be in very bad shape at the moment for space work.

Mr. ANFUSO. Are you recruiting, for example, international scientists from other friendly countries to assist in this research program?

Mr. KIMBALL. As far as we are concerned, no. In the IGY there was, of course, a cooperative effort with other countries.

Mr. ANFUSO. IGY suggested that, didn't it?

Mr. KIMBALL. Yes, sir.

Mr. ANFUSO. Do you know whether anything has been done since IGY for international cooperation in this field?

Mr. KIMBALL. I can't answer that.

Mr. ANFUSO. You regard that as being very important, don't you?

Mr. KIMBALL. In our particular case, no, because most of the work we are doing is classified. If the Government sees a need for foreign representatives to know, they can send them to our plant and tell us what we should tell them.

Mr. ANFUSO. Would you say that the Government certainly would profit by such international cooperation?

Mr. KIMBALL. Possibly.

The CHAIRMAN. Mr. Wolf?

Mr. WOLF. Mr. Chairman, I just got here.

The CHAIRMAN. Mr. Karth?

Mr. KARTH. Mr. Kimball, do you have any estimate of how much money it would require for your company to do the research in finding out whether or not nuclear propulsion is a feasible field to enter into?

Mr. KIMBALL. I couldn't give an estimate on that. It would be a substantial amount of money. There has been work done on nuclear rockets, but it hasn't been of a very large magnitude. There was some question in some of the scientists' minds as to whether it was practical or not.

Mr. KARTH. You have no estimate as to how much money you would need to find out whether or not we could reach the point where you felt it was going to be practical or not?

Mr. KIMBALL. As a guess, I would say of the order of magnitude of $50 million spent over a number of years.

Mr. KARTH. Would it be the same for investigating the research work on the electrical propulsion system?

Mr. KIMBALL. I would like to have Dr. Carter answer that, because he is more familiar with it than I am.

Dr. CARTER. I think that on these electrical propulsion systems that a program—an initial program—over possibly a 3- to 5-year period of the order of $50 million could undoubtedly provide a lot of answers. On the research end of things, the cost is not very much.

After you have an idea which looks as though it is going to be feasible, and you get into the development stage, that is probably going to cost 10 times as much as the research.

Then after you have something developed to where it looks as though it is going to be practical and you want to actually employ it, that conversion to production, so to speak, is probably going to cost 10 times as much as the development.

Mr. KARTH. I understand that. But my primary interest was whether or not you had made any determination on how much money it would cost to first decide through your research whether or not this was a feasible field to enter into, whether or not it was practical, whether or not it would work. This, of course, would involve only the research.

Do you have an estimate as to how much money it would cost your company in the field of research to decide whether or not it

is practical to go ahead with an electrical propulsion system and a nuclear propulsion system?

Dr. CARTER. And nuclear?

Mr. KARTH. And/or both. Could you give me a figure on each one?

Dr. CARTER. I would say to investigate the possibility of the electrical systems, and hope to come up with one out of the possible half dozen or so that we have thought of, would probably be a $10 million job.

Mr. KARTH. How about the nuclear field?

Dr. CARTER. On the nuclear field, that has proceeded far enough so that this really small-scale experimentation is no longer possible. It has to get up into a somewhat larger scale. I think something on the order of $50 million.

Mr. KARTH. If you spent $50 million, you feel that with a fair degree of assurance you could then at least be able to decide whether a nuclear propulsion system is feasible is that correct, sir?

Dr. CARTER. I think it would be.

Mr. KARTH. And as to the electrical propulsion system, you feel after spending $10 million, you could then decide whether or not this field would be a feasible one, is that correct?

Dr. CARTER. I think so.

Mr. KARTH. Thank you, sir; that is all, Mr. Chairman.

The CHAIRMAN. Mr. Daddario?

Mr. DADDARIO. If we can follow Mr. Karth's line of reasoning here on the technical development program for an integrated electrical propulsion system, who would do it? Who would you say should handle this kind of development?

I would assume that when you say that "We have reached the point where this should be done," that you have done enough experimentation, at least at the thought level, so you can get into the basic research and development of this type of program.

Who should do it—NASA, the Government, or should it be parceled out on a contract basis to private industry?

What kind of thought do you have on the programs involved, either Mr. Kimball or you?

Mr. KIMBALL. I think the companies that have the capability in that field, and the universities that have the capability, should be evaluated and a decision made possibly to split it between two companies—two companies or two universities that would have the greatest capability in those fields.

Mr. DADDARIO. Has there been enough experimentation in this field, up to this point, to demonstrate which companies or which universities should get into this program?

Mr. KIMBALL. I would think so, yes, sir. There are a half a dozen companies that have worked in this field and have some competence and capability.

Mr. DADDARIO. Who would you say those universities or companies are, Mr. Kimball?

Mr KIMBALL. I would rather let whoever had to pick them say.

Mr. DADDARIO. The reason I am concerned about that is that I think we get back, in all of these discussions, to something Mr. Teague talks about. We get into these more involved types of systems and

propulsion, and we get into more experimentations—we have more people being involved. It seems to me, too, there is more duplication.

I wonder, when you hit the area where you said that there is a wide flow of information and need to know, if you include in that, too, those industries which feel that they should keep their experiments to themselves and not get involved in Government grants because of the fact they would like to control their proprietary rights. Therefore in some areas, in nuclear areas, for example, I would imagine that there are developments going on where private industry is very selfish—not selfish, very careful of its developments in order to protect the rights for patents and other purposes.

Mr. KIMBALL. I would think the nuclear field and the rocket propulsion field is pretty generally known—people know what each is doing in the field generally. We don't think that other people in the field know everything we are doing, but they know generally what we are doing. Certainly the military departments know in detail what we are doing.

Mr. DADDARIO. You don't think in this field the traditional problem of proprietary rights within industries as they have competed to maintain their research and development really takes——

Mr. KIMBALL. I think generally as far as the military are concerned, they respect the proprietary rights of the companies.

The CHAIRMAN. Mr. Moeller.

Mr. MOELLER. Mr. Kimball, I would like to ask just one question following what Mr. Anfuso talked about before. You say your company's investment amounts to X number of dollars, and the Government likewise has X number of dollars invested. Who has the title to this investment? Does your company have it?

Mr. KIMBALL. No, no. The things the Government put in, they have title to.

Mr. MOELLER. They hold title to it?

Mr. KIMBALL. They hold title to it.

Mr. MOELLER. If you should buy it someday, it is up to you to pay the price of whatever they want to sell it to you for?

Mr. KIMBALL. Yes.

Mr. MOELLER. Otherwise it is definitely kept separate?

Mr. KIMBALL. In great detail.

The CHAIRMAN. Mr. Roush?

Mr. ROUSH. Mr. Kimball, is your company doing any work in nuclear propulsion?

Mr. KIMBALL. We have a nuclear division. We are doing—yes; we are doing some work in nuclear propulsion.

Mr. ROUSH. Is this work just research work, or is there any practical experimentation?

Mr. KIMBALL. There is some experimentation going on. Project Rover, I think, is classified. I will be glad to supply that information, but I don't think I can do it publicly.

Mr. ROUSH. I didn't realize it was classified, because I received through ordinary mail comments concerning this project. That was the reason I was asking about it.

Mr. KIMBALL. We have done some work on Project Rover. We have done some independent thinking on nuclear propulsion systems as well.

Mr. ROUSH. I had better quit, Mr. Chairman.

The CHAIRMAN. Mr. Kimball, let me ask you a question or two. Where is your plant located—California?

Mr. KIMBALL. Yes, sir.

The CHAIRMAN. Do you have any other auxiliary plants located elsewhere?

Mr. KIMBALL. We have a plant in Sacramento, and Azusa, Calif., and our nuclear activities are near Oakland—San Ramon. We also have an eastern plant in Frederick, Md.

The CHAIRMAN. What kind of plant do you have at Frederick, Md.?

Mr. KIMBALL. We have a small plant in Frederick, Md.

The CHAIRMAN. What is the size of your overall operations? About how many people do you employ?

Mr. KIMBALL. About 18,000 people.

The CHAIRMAN. In all of the plants. Your investment is about $100 million, you say?

Mr. KIMBALL. Less than that. Around $80 million.

The CHAIRMAN. That represents your own investment?

Mr. KIMBALL. No, that represents our investment and the Government's investment. I would be happy to supply those figures for you in detail for the record.

(These data are as follows:)

Aerojet has presently invested $31,463,181 and the Government has invested $52,007,980 for a combined gross property value of $83,471,161. These figures do not include such items as special test equipment, tooling, etc. which may have been acquired under supply contracts from the Department of Defense.

Mr. ANFUSO. Would you yield, Mr. Chairman?

The CHAIRMAN. I promised to yield to Mr. Miller. Mr. Kimball is probably from his home State. He wants to say a word to compliment him.

Mr. MILLER. I was hoping to get on last.

The CHAIRMAN. Mr. Anfuso.

Mr. ANFUSO. Mr. Kimball, is there anything to prevent you from getting some of this work for putting up a plant on the northeast seaboard in order to give some work there?

Mr. KIMBALL. No, sir.

Mr. ANFUSO. Have you given thought to that?

Mr. KIMBALL. We have looked at a number of places at different times. It happens we had the technical people in California, so we naturally expanded there.

Mr. ANFUSO. Have you thought of subcontracting any of this work?

Mr. KIMBALL. We subcontract a great deal of our work all over the country. Half of our sales dollars are subcontracted all over the country.

Mr. ANFUSO. You are willing to listen to people regardless of what part of the country they come from?

Mr. KIMBALL. Oh, we have got much work going on in all of the different places in the country.

The CHAIRMAN. Mr. Miller.

Mr. MILLER. I just wanted to say for the benefit of my colleagues that Mr. Kimball was a great Secretary of the Navy—we had the privilege of serving with him. As head of Aerojet, I think you have heard the statement that this company, General Tire, took over Aerojet—I believe I am right, Mr. Kimball, it was organized on rather a

voluntary, almost a nonprofit basis by a group of scientists at California Institute of Technology.

Mr. KIMBALL. Aerojet was originally organized by a group under Dr. von Karman to manufacture some of the things that had been developed at Cal Tech because Cal Tech could not go into the manufacturing business.

Mr. MILLER. It was never much after profit?

Mr. KIMBALL. We try pretty hard to make a profit, Mr. Miller. We have to.

Mr. MILLER. But all of your profits to date have been plowed back——

Mr. KIMBALL. Right back into the building.

Mr. MILLER. No dividend has ever been paid to the stockholders?

Mr. KIMBALL. I think a small dividend was paid back in 1947 or 1948. But at that time we bought most of the other stockholders out because we told them we couldn't pay any dividend. I must admit I don't know where the stock is.

The CHAIRMAN. How is the Government to get any money out of space for taxes then, under that sort of arrangement?

Mr. MILLER. Thank you.

The CHAIRMAN. Any questions over here, Mr. McDonough? You just came in. Mr. Van Pelt?

Mr. VAN PELT. No.

The CHAIRMAN. Mr. Wolf.

Mr. WOLF. What I am curious about, Mr. Kimball, do you have any facility in your company to take advantage of the findings of CIA or any other way to equate what we learn from Russia to help you with your research.

Mr. KIMBALL. Yes, sir.

Mr. WOLF. Can you tell us a little in open session about how you use this material, or what you get?

Mr. KIMBALL. I think I could say we haven't found anything that the Russians have done that we haven't already known.

Mr. WOLF. That is a good answer. Would you care to compare their propulsion systems and their fuels a little bit with ours? I notice there is something in the testimony that did this.

Mr. KIMBALL. I can't give you any details on that. I think we are at least up to them now on liquid rocket engines and I think we are considerably ahead of them on solid rocket engines. That is my opinion.

Mr. MCDONOUGH. Mr. Chairman, I just want to welcome Mr. Kimball here as a California native—I don't know about "native," but at least a resident——

Mr. KIMBALL. Forty-five years.

Mr. MCDONOUGH. That is a native.

The service he is rendering I am sure is very beneficial. I didn't hear your testimony. I was tied up with a meeting of the Immigration and Naturalization Committee. But I am curious to know what progress we are making in the fuel to produce a million-pound thrust?

Mr. KIMBALL. You can produce a million-pound thrust. Another company has a contract to develop a million-pound-thrust engine. I think they will be speaking to that. I think we can make a million-pound-thrust engine, either liquid or solid. I know we can.

Mr. McDONOUGH. You haven't got the engine ready yet?

Mr. KIMBALL. No.

Mr. McDONOUGH. What is the maximum that we have at the present time?

Mr. KIMBALL. The maximum we have is a 200,000-pound-thrust engine.

The CHAIRMAN. Any further questions? If not, we thank you very much, sir. You have made a great Secretary of the Navy. If you are imparting the same genius and ability to your business as you did to the Navy, I think you will get along all right. We certainly thank you for coming here.

Mr. KIMBALL. Thank you.

The CHAIRMAN. We have several other witnesses here. The next one this morning is Dr. Ritchey, vice president and technical director of the Rocket Division of Thiokol Chemical Co. Our staff has called my attention to the fact that we have Mr. Samuel K. Hoffman of Canoga Park, Calif., the North American Aviation Co., first. So we will hear him and then we will hear you next, sir.

Mr. Hoffman, if you will come forward, sir, we will have your statement now. I want to say this, to the members, too, that we have to adjourn promptly at 12 to get over for the Consent Calendar.

Do you have a prepared statement, Mr. Hoffman?

Mr. HOFFMAN. I have a prepared statement, and you have copies of it. Rather than read it, I will work from some charts here.

The CHAIRMAN. That's fine. It will be interesting to everybody.

STATEMENT OF SAMUEL K. HOFFMAN, VICE PRESIDENT, NORTH AMERICAN AVIATION, INC., AND GENERAL MANAGER OF THE ROCKETDYNE DIVISION

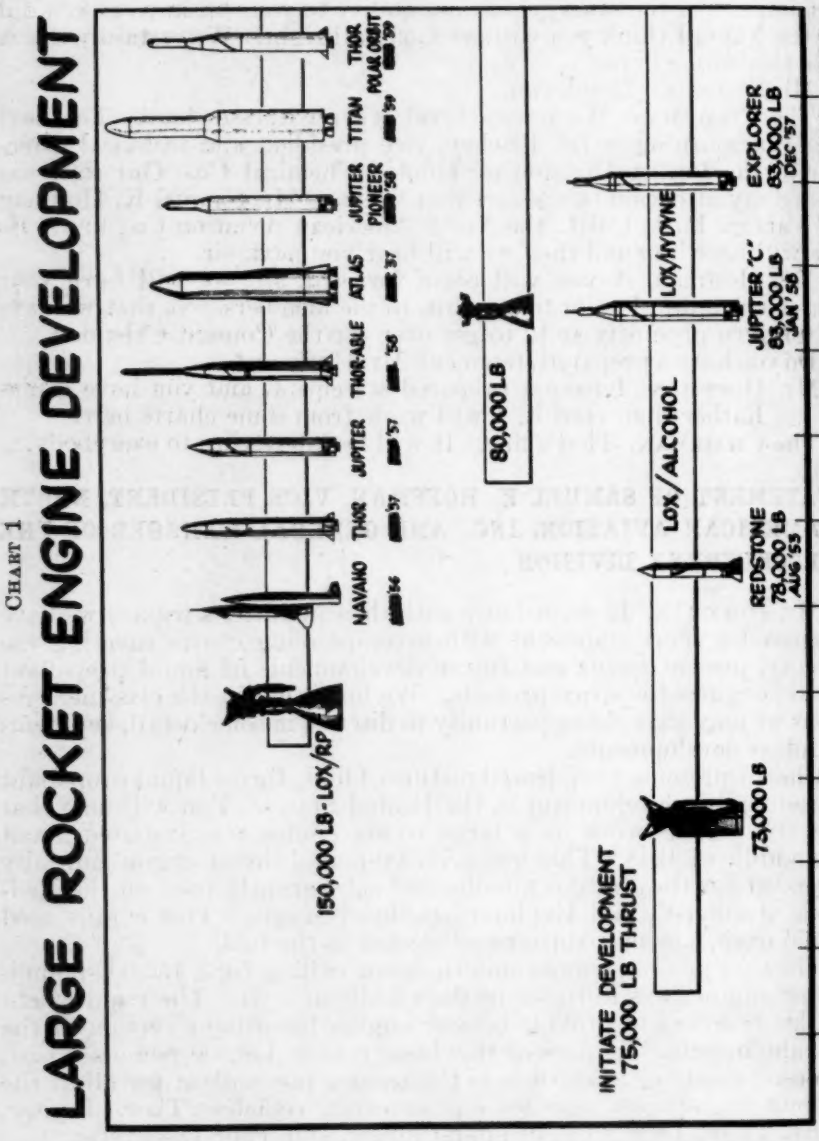
Mr. HOFFMAN. In accordance with the committee's request we have prepared a short statement with accompanying charts covering the history, present status and future developments of liquid propellant rocket engines for space projects. We hope that in the classified sessions we may have the opportunity to discuss, in some detail, key items in future developments.

Chart 1 presents a condensed picture of high-thrust liquid propellant rocket engine development in the United States. You will note that the first serious work on a large rocket engine was initiated about the middle of 1948. This was a 75,000-pound-thrust engine, initially intended for the Navaho missile, and subsequently used on the Redstone, Jupiter-C, and Explorer satellite projects. This engine used liquid oxygen as the oxidizer and alcohol as the fuel.

The next project, a more ambitious one calling for a 150,000-pound-thrust engine, was initiated in the middle of 1951. The requirement in this case was to provide booster engine for a later version of the Navaho missile. Engines of this basic rating, 150,000-pounds thrust, are used singly or in clusters as the booster powerplant for all of the current high-thrust missiles and research vehicles: Thor, Jupiter, Atlas, Titan, Thor-Able, Jupiter-Pioneer, and Thor-Discoverer.

The next significant engine development was initiated in 1954: 80,000-pound-thrust sustainer engines for the Atlas and Titan ICBM's.

We may very quickly summarize this history by stating that three basic engines of 75,000-, 80,000-, and 150,000-pounds thrust, used singly or in clusters, provide power for our entire family of large missiles.



Mr. HOFFMAN. Proceeding from history into the present status, we have on chart 2 a comparison of the original German V–2 liquid rocket engine and a current IRBM engine. Note that the thrust has been increased from 56,000 to 150,000 pounds. The two engines are shown to scale, and the relative reduction in size and installation dimensions is apparent. The engine thrust-to-weight ratio has improved approximately 245 percent. We get 245 percent more pounds of thrust for every pound of engine weight.

Efficiency, or specific impulse, has been increased approximately 30 percent. The technical expression, "specific impulse," is simply the pounds of thrust an engine delivers for each pound of propellant burned per unit of time—somewhat the same as "miles per gallon" on one's car.

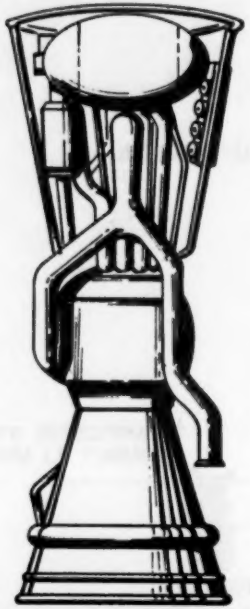
Perhaps this efficiency figure in itself may not seem too important, but let us assume a given missile is unchanged in all respects except for substitution of an engine having an improvement of 30 percent in specific impulse, that is to say, efficiency. The range of this missile, with the improved engine, carrying the same payload, would be at least doubled.

If we were to capitalize on this improvement in another way, we could carry at least 3½ times the original payload over the original range.

These are all measures of the improvement of the state-of-the-art during the relatively short period of time this type of engine has been under intensive development.

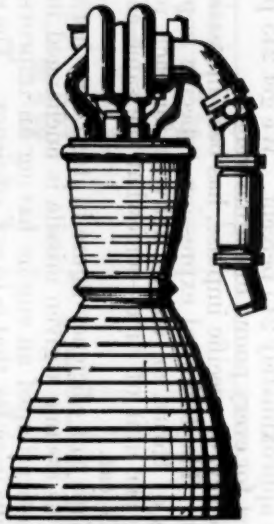
CHART 2

LIQUID ROCKET ENGINES
STATE OF THE ART



1945-V-2
56,000-LOX/ALC

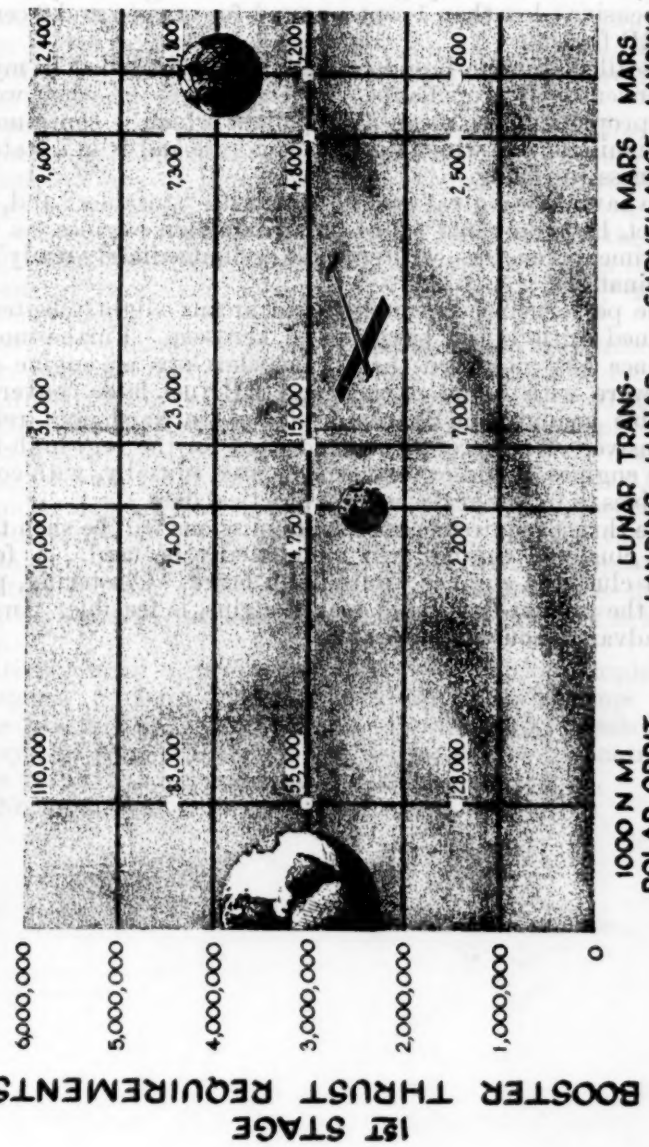
IMPROVEMENTS	
ENGINE THRUST/WT RATIO	245 %
EFFICIENCY (SPECIFIC IMPULSE)	80%
RANGE OR PAYLOAD	125% 255%



1958 IRBM
150,000-LOX/RP

Mr. HOFFMAN. Before discussing a program for the future, we should take a quick look at the engine requirements for space vehicles. Chart 3 shows first-stage booster engine thrust requirements for various missions. In a soft lunar landing, as an example, the first-stage booster would require a little over 1 million pounds' thrust to land a ton on the moon. For five tons landed on the moon, the first-stage booster requirement would increase to 6 million pounds of thrust.

CHART 3



Mr. HOFFMAN. Space projects will require multistage vehicles. Chart 4 depicts a typical multistage vehicle together with the range of engine requirements applicable to each stage. Considering first the booster stage, in current as well as future missiles, the thrust requirement will vary from perhaps 80,000 pounds to 6 million pounds or more.

Engine efficiency is relatively less important in first than in upper stages. For reasons of cost and convenience, conventional propellants of intermediate performance will be used. The basic conventional propellant combination used today is liquid oxygen and RP fuel, which is essentially kerosene. Performance is good, and both propellants have the very great merit of being readily available and inexpensive—less than 1 cent a pound for oxygen and 2 cents a pound for RP fuel.

So-called storable liquid propellants are included in my definition of conventional propellants. By common usage when we say "storable propellant" we mean a propellant which is continuously stored in the missile, one which doesn't evaporate and is in a state of instant readiness for firing.

We have done a great deal of work with "storables" and, as a matter of fact, have operated all of our production engines, as well as our experimental engines, with storable or "immediately ready" propellant combinations.

The performance is equal to and in fact slightly better than that obtained with liquid oxygen and kerosene. Furthermore, our experience has confirmed that if one develops an engine system and hardware with liquid oxygen and RP fuel later conversion to the storable combination is rapid, straightforward, and relatively inexpensive. We therefore conclude that for the very high-thrust first-stage engines, liquid oxygen will be used initially, with conversion to storables to follow at the earliest practical date.

The thrust requirements of space missions will be such that in most cases clustered engines will undoubtedly be used. A few remarks about clustered engines would be in order. Clustering, particularly with the present-day liquid rocket engine, is feasible. In many cases it is advantageous and desirable.

I think a rough analogy might be the case of the passenger car engine. No one really cares whether they are traveling in a car with a six or an eight cylinder engine. On the other hand, a passenger car with an 80-cylinder engine would be entirely impractical. Much the same reasoning applies here.

Depending on the amount of thrust you need, a reasonable number of clustered engines is very practical—and indeed there are some concepts that make it very advantageous. For the ambitious projects where the thrust is extremely high, it will be necessary to cluster larger engines to avoid the situation of a car with 80 cylinders. As long as we keep it down to the six and eight cylinder class it will be fine.

Proceeding to the intermediate stage of the vehicle, the thrust will range from 10,000 to perhaps a million and a half pounds. In this and succeeding stages efficiency becomes progressively more important than in the first.

At this point, we have rather compelling reasons to utilize high-performance propellant combinations, particularly for future large-scale projects. Moreover, a new requirement appears—altitude start. High-energy propellants, with one exception, provide greater assurance of satisfactory high altitude ignition and eliminate the necessity for auxiliary starting systems. The reason for this is the fact that high-energy propellant combinations are "hypergolic," that is, they ignite immediately upon contact with each other.

High-energy propellants meet the very important requirements for upper stage engines: high performance, higher insurance for satisfactory altitude starting, and a simplified engine. These advantages outweigh the disadvantages of extra cost and handling complications. For at least certain applications clusters of engines will be desirable.

Final-stage thrust requirements will range from perhaps 5,000 to 15,000 pounds. High performance and altitude-start performance in this final stage are at a still greater premium than for the intermediate stages. In addition, two new requirements appear: the ability to start-and-stop at will, and the ability to throttle as desired. The use of high-energy propellant engines in this category is almost mandatory.

For relatively small upper-stage engines we envision simple pressurized systems. Systems of this type require no turbopump. They will utilize pressure tanks, propellant valves, thrust chamber, and a control system compatible with the degree of thrust control desired. The result is a very simple, effective space engine.

(Chart No. 4 follows:)

CHART 4

TYPICAL SPACE PROPULSION REQUIREMENTS

TYPICAL FIRST STAGE CHARACTERISTICS

- THRUST (2,000-150,000 LB)
- ALTITUDE START
- RESTART
- HIGH ENERGY PROPELLANTS
- SIMPLE PRESSURIZED SYSTEM UNDER 50,000 LB THRUST

TYPICAL INTERMEDIATE STAGE CHARACTERISTICS

- ALTITUDE START REQUIREMENTS
- THRUST (10,000-1,500,000 LB)
- HIGH ENERGY PROPELLANTS
- PROBABLY CLUSTERED

TYPICAL BOOSTER ENGINES CHARACTERISTICS

- HIGH THRUST (80,000-6,000,000 LB)
- CONVENTIONAL PROPELLANTS
- CLUSTERED

Mr. HOFFMAN. This analysis of engine requirements and attendant engine specifications leads one to expect future engine developments as shown on chart 5. There has been public announcement of a contract for an engine in the million pound class. Two versions of the 150,000 and 80,000 pound thrust engines are available. I would envision a requirement for an engine intermediate between the 150,000-pound and 1-million-pound thrust basic engines, and, in addition, basic low-thrust pressurized high-energy propellant engines.

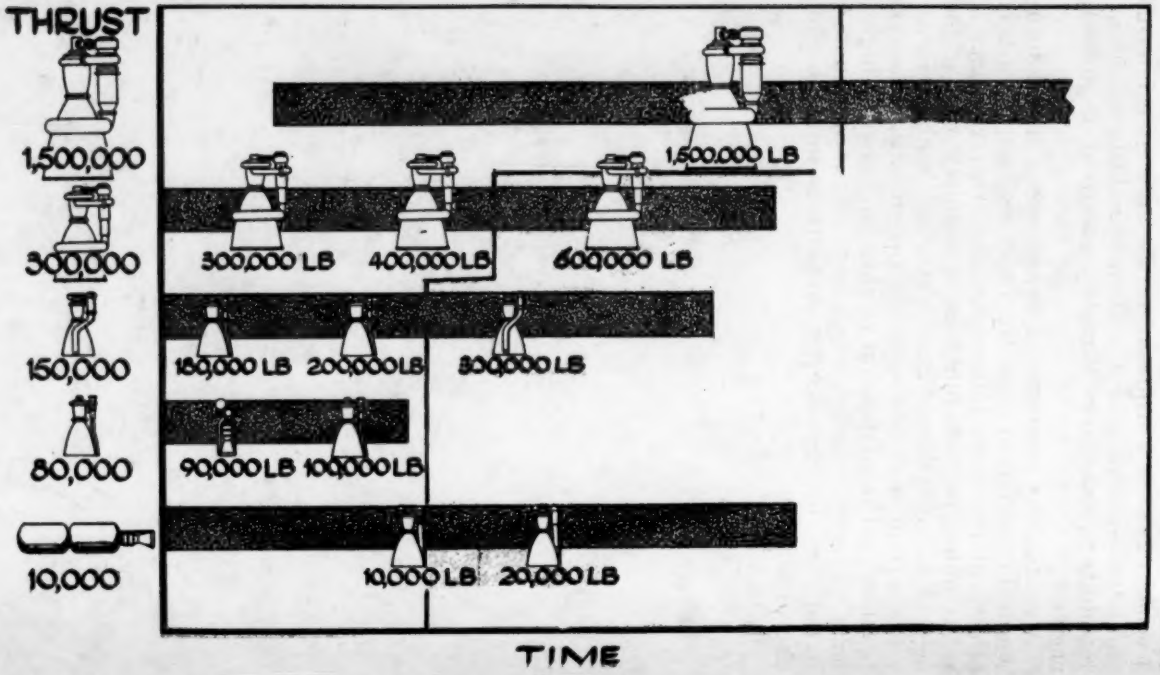
A continuous program of development would insure that over a reasonable period of time the basic engines in each category would achieve about twice their original thrust ratings. These developments would provide our missile industry with a good selection of engines for missiles or missile-staging combinations.

Concurrent with the uprating program in some cases, in sequence in others, is the adaptation of these engines for high-energy propellants. The step-shaded area shows the approximate timing for the introduction of high-energy propellants into the program for each class of engines.

(Chart No. 5 follows:)

CHART 5

BASIC ENGINE THRUST AND PERFORMANCE UPRATING



Mr. HOFFMAN. A degree of improvement in efficiency, or specific impulse, is obtained in the thrust uprating program, retaining conventional propellants. However, the maximum is obtained when, in addition, we introduce high-energy propellants. In chart 6 the red bars show the improvements to be obtained with various high-energy propellant combinations. In comparison with current conventional propellant combinations we may expect an improvement in altitude performance from approximately 350 to approximately 450 pounds of thrust per pound of propellant.

The green bars show the increase which may be expected for the storable propellant combinations. As has been mentioned before, current storable propellant combination performance is equivalent to that obtained with liquid oxygen and RP fuel. With continuing research and development we anticipate that a storable combination with performance within 10 percent of that achieved with the best high-energy propellant combination is possible.

(Chart No. 6 follows:)

CHART 6

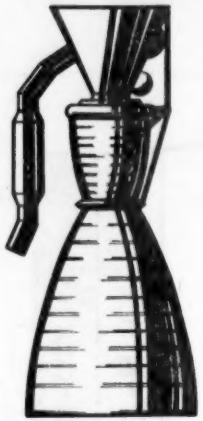
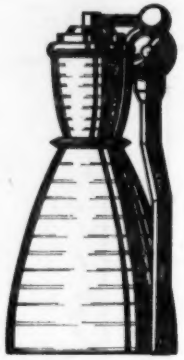
LIQUID PROPELLANT PERFORMANCE GROWTH

Mr. HOFFMAN. Last, but by no means the least important effort in the liquid rocket engine program is that of simplification. In chart 7 are shown three stages of a simplification program: 1955 models in operation today (model T versions); simplified engines in the early production stage (1958 model); and a 1960 model. Note the successive reduction in major components from 88 to 33 to 5 respectively. Each reduction is a great forward step in achieving further overall engine reliability.

(Chart No. 7 follows:)

CHART 7

ENGINE SIMPLIFICATION AND IMPROVED RELIABILITY

1955 MODEL	1958 MODEL	1960 MODEL
		
NUMBER OF COMPONENTS: 88	33	5
NUMBER OF MAJOR COMPONENTS: 8	3	2

Mr. HOFFMAN. In conclusion, liquid rocket engines provide by far the highest current as well as future potential performance in terms of thrust developed per pound of propellant. They provide the possibility of virtually unlimited control of thrust as well as start and restart capabilities. Duration or period of operation is limited only by availability of propellants.

A final very practical and unique feature I would like to emphasize. A great deal of thought is being given to the recovery and reuse of these valuable space vehicles. It is in this area of recovery potential that liquid propellant engines are unequalled.

On chart 8 we have depicted an artist's conception wherein a missile takes off vertically and is returned to land in the optimum vertical position. Eventually we shall see missile take off and return to the launching site in essentially this manner. Maintenance crews will check them out, tankers will pull up for the refueling operation, and the missile will be ready for the next flight into space.

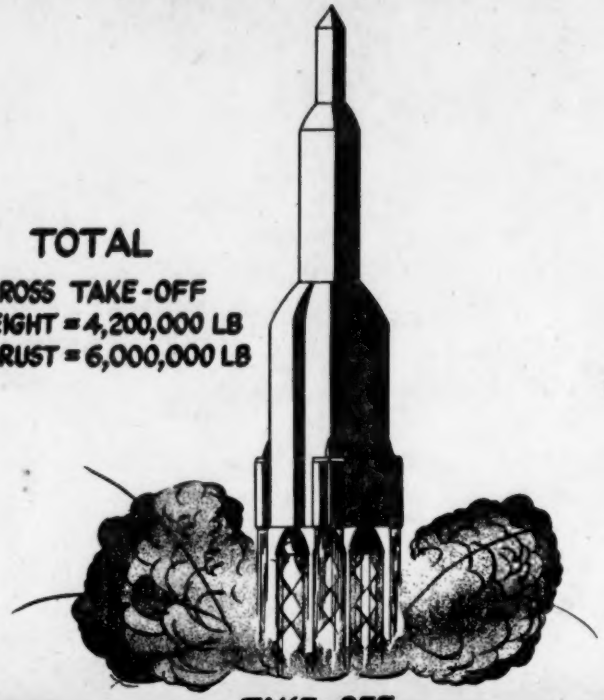
(Chart No. 8 follows:)

CHART 8

RECOVERABLE BOOSTER

TOTAL

GROSS TAKE-OFF
WEIGHT = 4,200,000 LB
THRUST = 6,000,000 LB



TAKE-OFF

BOOSTER

GROSS LANDING
WEIGHT ≈ 200,000 LB
THRUST ≈ 220,000 LB
(TURBOJET)

LANDING

Mr. HOFFMAN. We have been asked to cover history, present status, and development of liquid propellant rocket engines. So we are more specific than Mr. Kimball.

I will shorten this—it is covered in the statement—by simply pointing out that our entire family of current missiles is taken care of with three basic sizes of liquid propellant rocket engines. The 75,000-pound engine, two makes of 80,000-pound engines, and again, two makes of 150,000-pound basic engines.

Going on to the status, we show here for the purpose of comparison, a German V–2 engine, and a current 150,000-pound basic engine, the engines that currently power all of our existing missiles.

Mr. MILLER. Are they drawn to size or scale?

Mr. HOFFMAN. These are drawn to scale, so they will give you an idea of the reduction in size that has been achieved. The thrust has been increased from 56,000 to a basic 150,000 pounds thrust. I have a model here of the current engine which might give you a little better physical idea of the engine.

The CHAIRMAN. Where is the model?

Mr. HOFFMAN. It will be right up.

The engine thrust-to-weight ratio over this period of time has been improved some 247 percent. Expressed another way, we get three and a half times more pounds of thrust for each pound of engine weight than on the German engine. Three and a half times more pounds per pound of engine weight today.

The efficiency or specific impulse has been increased 30 percent. The technical expression "specific impulse" simply means the number of pounds of thrust one obtains for each pound of propellant burned per unit of time.

This is more or less akin to the miles per gallon on your car. So what has been achieved in this country during this period is that we got about one and a third times as much pounds of thrust for each pound of propellant burned as was achieved in the engines of 1945. This is reflected in the range and payload of a given missile.

For example, if you were to take a missile, unchanged in any respect, except to put an improved engine of this type in, more efficient, with higher specific impulse—the range would be improved 125 percent; the payload, 285 percent as a minimum.

Expressed another way, this original missile with the same payload would go better than twice as far. Or if you wish to capitalize on this in another way, the same missile could carry at least 3½ times the original payload over the original range.

So you can see that, particularly in missiles, the improvement in efficiency or specific impulse pounds of thrust per pound of propellant burned, is extremely critical.

Before we go on to the prognostication of future developments, it will be well to look at the requirements and specifications for the engines. First we will take up the matter of boosters.

The CHAIRMAN. Can everybody see the chart? I believe everybody can see it, sir.

Mr. HOFFMAN. Here we have shown booster thrust plotted with respect to certain missions. As you can recognize, this is a generalized chart and, for different designs, these numbers would not be accurate. But they do give a feeling for the range.

Take, for example, a lunar landing. The only one that really counts is a soft landing, one that you can walk away from. In the case of a lunar landing it would require in the order of a million pounds of thrust to land a ton on the moon.

The CHAIRMAN. Wait a minute, you said to land it, or to get it up there?

Mr. HOFFMAN. Oh, no; to land it.

The CHAIRMAN. A million pounds of——

Mr. HOFFMAN. Of thrust per ton.

The CHAIRMAN. That would be in addition to getting it up to the moon?

Mr. HOFFMAN. Yes, you would have to slow it down and get it on the moon without it being splattered, so to speak; a so-called soft landing.

The CHAIRMAN. It would take a million pounds simply to make the soft landing up there?

Mr. HOFFMAN. Yes, for 1 ton.

The CHAIRMAN. How much would it take to get the rocket to the moon?

Mr. HOFFMAN. This million pounds of thrust.

The CHAIRMAN. A million would cover getting it up there and bringing it in for a soft landing?

Mr. HOFFMAN. Yes, and you would have subsequent stages, of course, to land it on the moon. I will cover that shortly.

Mr. ANFUSO. Mr. Chairman, why would you need a thrust to have a drop? I don't understand.

Mr. HOFFMAN. If you didn't have a thrust, once you got into the gravitational field of the moon, it would accelerate and land so rapidly it would be destroyed. So to simply hit the moon takes far less than this. But to aim at the moon and land a weight on the moon, perhaps eventually a man, you must land it, a so-called soft landing, and for this it takes extra energy.

Mr. MCDONOUGH. As I understand, the million-pound thrust is for delivery. It is not for landing.

Mr. HOFFMAN. This is correct.

Mr. MCDONOUGH. That is 1 ton delivered to the moon and then you have retrorockets to land it?

Mr. HOFFMAN. That is correct. The million pounds is required to get out of the earth's gravitational field, get into the vicinity of the moon, and then these smaller engines that have been mentioned before—and incidentally, as I understand on Wednesday and Thursday respectively there will be—and we are prepared to discuss—nuclear and electrical engines. So I can't go into those now unless you wish me to.

I am speaking now, trying to establish the thrust requirements for the first or booster stages.

For 5 tons it goes up roughly proportional, 6 million pounds of thrust per booster. So you can summarize, first stage booster requirements for this kind of mission in the range of a million to 6 million pounds of thrust, depending on the load you want to land on the moon.

Similarly, other missions are on the chart, and I can't go into them. I hope this gives you some feel for why these large thrusts are required.

For these space missions, multistage missiles will unquestionably be required. So we have shown here a typical staged missile. This one happens to be three stages. It could be somewhat fewer or more. Taking each stage separately, starting with the booster stage, we have already discussed that 6 million pounds of thrust is a reasonable expectation.

Considering current missiles, they go as low as 80,000 pounds for some applications, small payloads, and not making a soft landing on the moon.

So we could bracket our first stage thus, 80,000 pounds to at least 6 million pounds.

On the first stage, the efficiency or specific impulse is not as critical as on succeeding stages. As you go up, the requirement for efficiency becomes more critical. A better way to express that might be if you put a pound here, you have to add 10 pounds here and 100 pounds here, because when you take off, this is dead weight, and it takes more propellant and missile down here to lift it.

I hope I make it clear that up here you need very efficient engines, because their efficiency or lack of efficiency means that you have to multiply the capacity for the lower stages to lift it up.

In any event, on the first stage efficiency is less critical than on succeeding stages, so here we envision conventional propellants. By conventional propellants, I refer basically to liquid oxygen and kerosene or, as I will call it later, RP fuel. This propellant combination is intermediate in performance.

However, it does have the very great merit of being extremely cheap. Liquid oxygen, one cent a pound—under one cent a pound. RP fuel, 2 cents a pound. And a good performing propellant.

It does have one disadvantage, which I think pertains mainly to military application. It is cryogenic. The liquid oxygen boils off, and without extra equipment, which can be provided if desired, without this extra equipment it is not immediately ready for a firing.

So now enters into the picture what we call storables. This is a misnomer really but we don't have a better name for storable propellants. What we really mean when we say storable is that it is a propellant that can be put in the missile, without doing anything to it in the way of extra equipment, that will store and stay in there indefinitely without boil-off and be ready for instant firing.

This is a characteristic of solids.

I include in my definition of conventional propellants, storables, which we now have. They are more expensive than current cryogenics. However, the performance today is equivalent to that we obtain with our liquid oxygen, RP combination—in fact, slightly better. Moreover, we have operated all of our production and experimental engines with a storable combination, and our experience has shown that with an engine well developed for liquid oxygen and RP, the conversion to a storable is rapid, relatively straightforward, and as a result relatively inexpensive.

So we envision in these large booster engines that they will use present conventional propellants and switch over to storables as rapidly as the facilities and availability of storables permit.

Mr. WOLF. Will you yield for a question, please?

Mr. HOFFMAN. Surely.

Mr. WOLF. Could you give us exactly the cost of these various fuels? I believe you said a cent a pound on this one item, and this is quite contradictory to what we got, I think, at Huntsville and Cape Canaveral, both as to the cost.

Mr. HOFFMAN. I am speaking of liquid propellants. These figures are accurate. It is under a cent a pound for liquid oxygen; 2 cents a pound for jet fuel or RP or kerosene.

The CHAIRMAN. What about solids?

Mr. HOFFMAN. Sir?

The CHAIRMAN. What about solids?

Mr. HOFFMAN. Well, solids, you run into a problem of whether you are speaking of the raw materials, after it is mixed, or as cast in the engine itself. I think perhaps on that I should yield to Dr. Ritchey in a discussion we are going to have tomorrow on solids. No doubt they will cover that.

The CHAIRMAN. We will wait until tomorrow to get that information.

Mr. WOLF. Thank you. I just wanted to clear that because we had been given some figures on liquid oxygen, for example, that were quite different from those you gave.

Mr. HOFFMAN. These figures are correct. I might add that the figures of under a cent a pound for liquid oxygen is based on a plant on site; and if my memory serves me correctly, I think in tank car-lots delivered to Neosho, Mo. The number that runs in my mind is 4 cents a pound. This is small tank-car lots. I will be glad to send you that data.

Mr. WOLF. Now I have got the answer as to why there was a difference in price, too.

Mr. HOFFMAN. Delivery cost in small lots—4 cents.

The CHAIRMAN. Are you through, sir? Proceed with your presentation of your charts.

Mr. HOFFMAN. Finally a word about clustering. So much has been said about it, I think a little time would be well spent on it. Actually clustering, particularly with modernday liquid propellant engines, is not only feasible but in some cases actually desirable.

By having multiple chambers, you get your roll control without putting on separate roll control engines. In any event, a rough analogy, I think, could be made with your automobile.

No one really cares whether you go down the road in a six- or an eight-cylinder car. On the other hand, you would recoil in horror if you had to have an 80-cylinder engine. It would be entirely impractical.

Much of the same reasoning applies here. What you really want are large enough units so that you don't find yourself in the predicament of having in effect an 80-cylinder car, so that you can get, say, a million pounds of thrust with two or three present-day engines, very good. But not 80 engines, not 20, 30, or 40 engines.

Going on to the second stage, I have mentioned that performance becomes increasingly important. The thrust here will be less, range perhaps from 10,000 to 1.5 million pounds of thrust.

Now, a new requirement comes in, that of altitude start. Principally because of the very great premium on improved efficiency, but also influenced by the fact that high energy propellants facilitate

high altitude starting, we envision that as rapidly as possible these upper stage engines will use high energy propellants.

High energy propellants will give high performance in terms of pounds of thrust per pound of propellant. They will facilitate high altitude starting because they are hypergolic. That is, when two propellants impinge they immediately ignite so you can throw away ignition systems.

So high energy propellants here, smaller range of thrust requirements; and in certain cases for the more ambitious project at least, clustering of engines for the thrust required.

Going to the final stage—there might be several intermediate stages. Incidentally, here is where the first nuclear will come in as an intermediate stage engine. We believe very definitely it should be pushed.

Mr. ANFUSO. What did you say? I didn't get that.

Mr. HOFFMAN. Nuclear engines will find their first use in second stage applications. It will make the first stage smaller, enabling you to do more ambitious missions with an upper stage.

Mr. MOELLER. May I ask a question at this point?

The CHAIRMAN. Mr. Moeller.

Mr. MOELLER. Using nuclear at the second stage, would that also eliminate to some extent the dangers of radiation?

Mr. HOFFMAN. This would be one of the reasons why we say it will be used second stage. Incidentally, another reason you will appreciate—I can't go into all the reasons—why we wouldn't use high energy in the first stage is because in general, high energy propellants have exhaust problems.

Mr. MCDONOUGH. Wouldn't you have a greater weight in that middle stage if you had nuclear propellants there?

Mr. HOFFMAN. This would be for the very large jobs or missions, ambitious missions, probably a half-million-pound-thrust engine.

Going to the final stage, all of the things I said regarding the intermediate stage still apply, but the thrust now is still further reduced, 2,000 to perhaps 150,000 pounds of thrust; and we have still another requirement added, restart and throttle.

For these last stages you want to start and stop the engine and throttle once you are out in space. High energy propellants here become practically mandatory.

Finally, in the third stage, for the small engines we would envision simple pressurized systems, no turbopumps, pressurized tanks, control valves on each of the two propellants, a thrust chamber, and a control compatible with the requirements imposed upon the engine for throttling, restart, and so on, which will vary from job to job.

I think I have covered the major items there. With the requirements established, we might go on to a prognostication of what the developments might reasonably be expected to be. As has been mentioned, a contract has been announced for an engine in the million-pound-thrust range. The use for it obviously is first stage boosters. As I mentioned previously, there are two 150,000-pound-thrust basic engines in existence. There are two 80,000-pound engines.

I would envision a requirement for an engine midway between the 150,000- and the 1,500,000-pound-thrust, put it down as 300,000. Also, a requirement for something in the order of a 10,000-pound pressurized engine with high energy propellant—the engine I mentioned last on the previous chart.

All of these engines can and should be uprated. Any basic engine has a capability in initial development through a continuing process of going to about twice its original thrust. So we could anticipate eventually doubling each one of these basic engines, up to as much as 2 million.

The other thing shown on this chart, this step-shaped area, represents where you might well expect to introduce high energy propellants into the picture. Immediately in the case of the small engine, and as you go up the line here, as soon as the basic engine is running well enough, you would use that hardware, put the high energy propellant adaptation in.

Two things happen when you upgrade an engine. One, the upgrading, per se; and the other is an improvement in efficiency which invariably follows along with the uprating.

However, to obtain the maximum in uprating, you change your propellants. On this chart we have shown in red here, the red bars, the improvement in altitude performance or pounds of thrust per pound of propellant burned that can be anticipated for liquid engines, roughly from 350 to 450 pounds of thrust per pound of propellant burned.

In the category of storables or instant ready propellants, as I mentioned before, today we have them with a performance equivalent to our LOX—liquid oxygen—with RP propellant. These green charts represent our estimate of what can be done with storables.

We expect them to go up to within 10 percent of what is achieved with high energy propellants. These are nice high-performance figures.

Last but not least, on simplication, here we show 1955 model engines that are flying today; also a 1958 model in early production; and the 1960 model now on the test stand. The number of components: 88, 33, and 5. I need not dwell on what this will do to further improve efficiency of engines.

Finally, in conclusion, to summarize all this, liquid rocket engines provide by far the highest current as well as future potential performance in terms of thrust developed per pound of propellant. They provide the possibility of virtually unlimited control of thrust as well as start and restart capabilities. Duration or period of operation is limited only by availability of propellants.

Finally, a very practical and unique application which applies essentially, I believe, only to liquid rocket engines, this ability to operate over and over again will be applied to recoverable missiles, particularly recoverable boosters.

Here we show an artist's concept of a missile taking off, the booster being landed in the optimum condition, vertically, all ready to take off again.

Personally, I am sure sometime in the future we shall be seeing these big space missiles take off and be recovered in a manner somewhat similar to this—the maintenance crew going over it, tightening up the pipes and valving, running your tanker trucks in, putting in perhaps our 1- to 2-cents-per-pound fuel, and being ready to take off again for another trip into space, pretty much the way airplanes take off today for San Francisco and Los Angeles.

Thank you, gentlemen.

Mr. McDONOUGH. How are you going to control the descent of that booster so it will be in good condition when it lands?

Mr. HOFFMAN. I mentioned this as an artist's concept. However, it is not entirely impractical. I think it might be done. I call your attention to the fact that we are engine men, basically, not missile men. However, the concept here, you see, when you take one off, it is very heavy and you need tremendous amounts of thrust—say your 6 million pounds of thrust. Here it is. The weight is 4 million pounds.

When a booster has done its job it is dropped, jettisoned. At that stage all the propellant has gone in it and the weight now drops way down, perhaps 200,000 pounds. You bring it back down probably with some parachutes. But we have shown here when it gets down close to the ground, you use air-breathing engines, perhaps in combination with smaller rocket engines.

The CHAIRMAN. Do you use that principle for a guided missile, to bring in a ballistic missile so you can slow it down and guide it toward its target?

Mr. HOFFMAN. No; you wouldn't want to do it for a guided missile. The only reason we have shown an air-breathing engine is as you bring it down and come back into the atmosphere, you have air; you get it for nothing; the weight is now very small.

The CHAIRMAN. Would it give you some ability to bring in, for instance, a missile delivering supplies or a missile delivering troops, which might be slowed down in the same way?

Mr. HOFFMAN. Perhaps, yes.

The CHAIRMAN. Then why wouldn't it be advisable to have a ballistic missile that could be slowed down so that you could bring it to the proper target?

Mr. HOFFMAN. I think there is some merit in it as applied to delivering supplies or troops.

The CHAIRMAN. Have you given it thought?

Mr. HOFFMAN. As I mentioned before, we are engine people. We have given a lot of thought to this and have been promoting the idea with missile people for the very obvious reason that it does capitalize to the fullest on this unique feature of the liquid engine, that you fire it once and bring it back down and simply pour fuel in it and take off again. It is a good concept.

The CHAIRMAN. I want to say to you, sir, that most of the committee has had the pleasure and the privilege of being at your plant in California and being briefed by your people there. We had a very successful trip and we learned a great deal from the operations of your plant. So we do appreciate your being back here with us this morning.

We have this morning two witnesses, at least, from Thiokol. If it is all right with the committee, I suggest that before we question Mr. Hoffman—because we all have a lot of questions to ask him—that we hear from Thiokol. They have come a long way. Then this afternoon I think we will have to meet for questioning.

I would like it that way because we have a better attendance in the morning than we do in the afternoon. I would like for the whole committee to hear Thiokol, too.

We have Dr. Ritchey from Thiokol, and Mr. Thatcher from Thiokol.

Dr. Ritchey, you are vice president and technical director of the Rocket Divisions of Thiokol Chemical Co.?

Dr. RITCHEY. That is right.

The CHAIRMAN. You are located in Bristol, Pa., and Huntsville, Ala.

Dr. RITCHEY. Bristol, Pa.

The CHAIRMAN. Mr. Thatcher is the manager, advanced engineering department, Reaction Motors Division of Thiokol from Denville, N.J.

Mr. THATCHER. Correct.

The CHAIRMAN. We are happy to have you gentlemen here. Do you have a prepared statement?

Dr. RITCHEY. I do not have. Mr. Thatcher does. I thought I would like to lead off with just a few comments on some things that I heard this morning and some other generalities, if I may.

The CHAIRMAN. All right, sir. We want the full committee to hear you and Mr. Thatcher both this morning. If you will proceed, we will appreciate it.

STATEMENT OF DR. HAROLD W. RITCHEY, VICE PRESIDENT AND TECHNICAL DIRECTOR, ROCKET DIVISIONS, THIOKOL CHEMICAL CORP.

Dr. RITCHEY. There were two or three matters brought up earlier which I would like to make a comment on very briefly. One of them is the matter of duplication of effort.

If we look at the general industrial complex in this country, we find a lot of duplication of effort. In particular, one of these is the oil industry where I think you can say there is a tremendous amount of duplication of effort. On the other hand, the oil industry and many others like it are pointed to as being a very, very healthy industry and a typical example of what private enterprise can do to increase or raise the standard of living.

I submit to you gentlemen the basic thesis that some duplication of effort, or perhaps we should beter call it competition, is very desirable in any activity; and this also applies to space technology.

The CHAIRMAN. What do you have in mind? Do you want more competition than you have now?

Dr. RITCHEY. I thought in hearing the discussion this morning perhaps there was some tendency to have less competition than there is at the present time. Certainly what we have now in general constitutes in my own opinion the minimum.

The CHAIRMAN. Just proceed, then, with your statement.

Dr. RITCHEY. The next one involves what appears to me, in looking back at our past history, as overconservatism and procrastination as representative of the general attitude of the country in this field, to the point where I think we could almost quote Shakespeare as being descriptive of the situation when he said, "Tomorrow and tomorrow creeps forth this petty pace"—or something to that effect.

What we have done is essentially this. We have always waited for something better. I think it is very worthy that we proceed aggressively with such advanced proplusion systems as nuclear-powered rockets and ion propulsion, and even gravity screens if you want to go that far.

But the danger is this: as we get almost to the point of having nuclear propulsion, someone says, "Let's wait for something else that is going to be a little bit better." If we keep on waiting we will never have what we need. If we are going to get into space in the next few years and really make progress in this field, we will do it with what we know how to do now, and that is our chemical propulsion systems.

I feel that we need to approach very aggressively the development of the chemical propulsion systems in the direction of the very best that we know how to do. There is a real danger that we will relax once more and say, "this particular thing is good enough for this particular mission that we have in mind," because 2 or 3 years from now we will conceive another mission, and we won't have the hardware we need to accomplish it.

With these general observations, I would like to turn the technical session over to Mr. Thatcher.

The CHAIRMAN. Mr. Thatcher, you have a prepared statement. Would you proceed, sir.

STATEMENT OF ALBERT G. THATCHER, MANAGER, ADVANCED ENGINEERING DEPARTMENT, THIOKOL CHEMICAL CORP.

Mr. THATCHER. Gentlemen, in the next 15 minutes or so I would like to transmit to you some of the general tends and recommendations regarding liquid rocket propulsion for astronautic applications. I suggest that to follow me better, perhaps you follow this black and white series of papers. I think there are six in all. And refer to them as figure 1 to 6 when I call it out in the text.

The first part of my paper will review some of the fundamental trends in liquid rocketry in order that the recommendations which follow can be fully appreciated.

I would like to introduce the subject of fundamentals by pointing out the significant influence of the two most important factors affecting the performance of a rocket vehicle. These are specific impulse (pounds of thrust per pound per second of propellant ejected) and propellant fraction (fraction of propulsion system weight which is usable propellant).

Figure 1 illustrates the effect of these parameters on the weight of payload which can be placed in a 300-mile orbit, with a vehicle approximately the size now in operation (200,000 pounds). The shaded area in the lower right denotes the regime of chemical rockets (solid and liquid). It is interesting to note the spread in orbital payload capability from the early 200 specific impulse chemical rockets to the potential 400 specific impulse systems—an increase of about 12,000 pounds of payload.

Right now as you know we are operating in the lower right hand quadrant of that sphere with our payloads in the neighborhood of several thousand pounds of payload.

However, since we expect to fully exploit the potential of the chemical systems in the foreseeable future, we must look to the nuclear heat exchange system for further payload capability. This type of rocket is in an entirely different specific impulse regime since it can utilize ideal working fluids.

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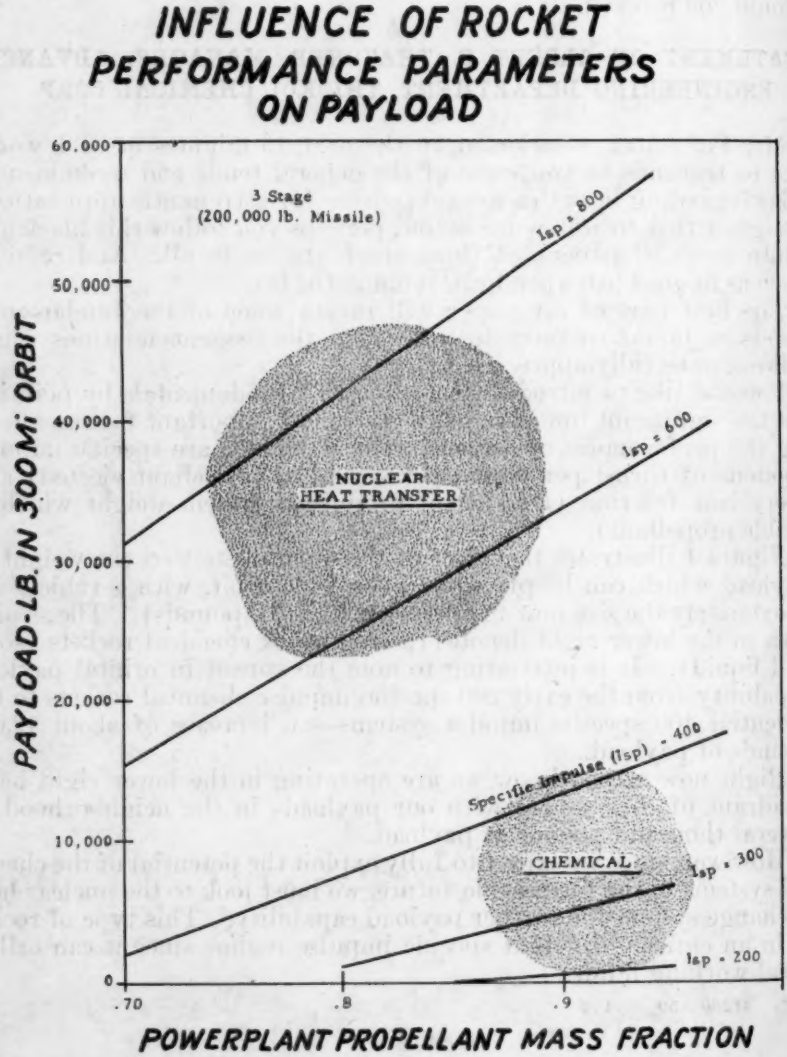
Again, one can appreciate the tremendous significance of specific impulse on payload capability, notwithstanding the predicted decrease in propellant fraction largely due to the heavy reactor weight. With this background on the general spectrum of thermodynamic expansion rocket cycles, we will proceed to probe further into the liquid rocket versions of the chemical systems, which is the only source of propulsion energy available to us in the immediate future.

First let us examine the progress being made in moving upward through the chemical system spectrum indicated on figure 1, by improvement of those two all important parameters—specific impulse and propellant fraction. Figure 2 plots the trends in these parameters over a 20-year period, eight of which are peering into the future.

(Figs. 1 and 2 follow:)

FIGURE 1



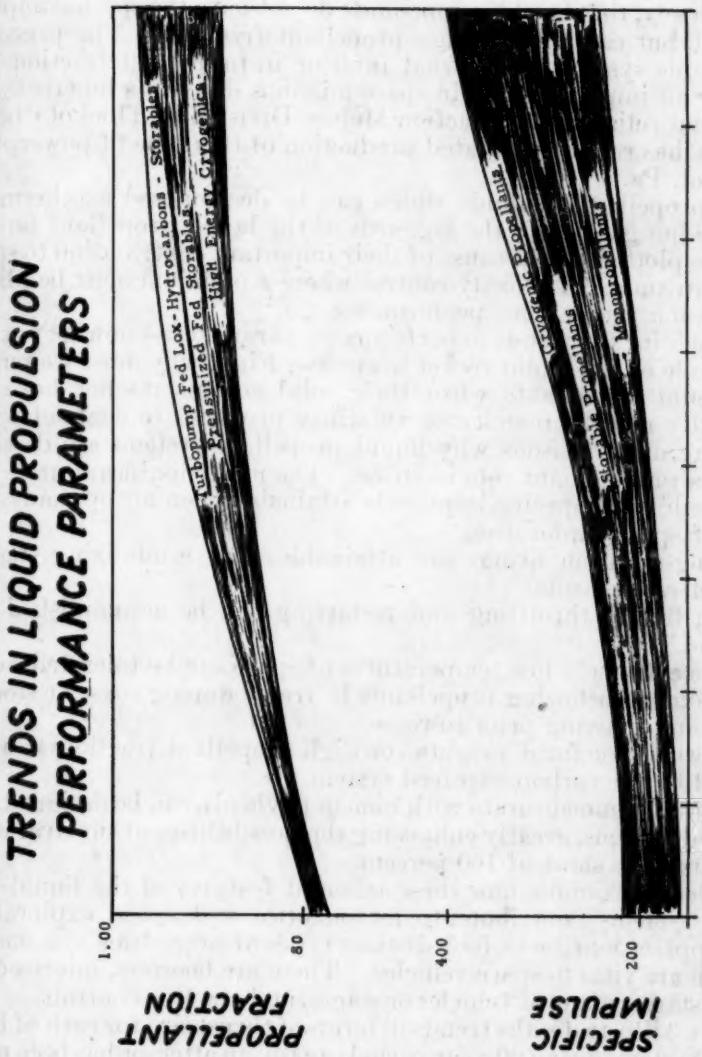

TRENDS IN LIQUID PROPULSION
PERFORMANCE PARAMETERS
Turbopump Fed Lox-Hydrocarbons - Storables
Pressurized Fed Storables
High Energy Cryogenics
Cryogenic Propellants
Storable Propellants
Monopropellants
PROPELLANT FRACTION
SPECIFIC IMPULSE
1.00
.80
400
200
'50
'55
'60
'65
YEAR

FIGURE 2

Mr. THATCHER. The cryogenics (liquified gases) offer the highest specific impulse potential, but due to their low bulk density, they require more hardware to contain and feed them to the combustion chamber. Hence their propellant fraction is limited even with the turbopump feed system. As you can see, they are the highest position in the lower specific impulse band, and they occupy the lowest in the top band of propellant fraction.

Conversely, the storable propellants do not have the specific impulse potential, but can achieve high propellant fractions. The pressure-fed storable system is somewhat inferior in propellant fraction, but can play an important role in space missions due to its inherent simplicity and reliability. Reaction Motors Division of Thiokol Chemical Corp. has recently initiated production of this type of powerplant in Bristol, Pa.

Monopropellants (liquids which can be decomposed exothermally to create hot gases) are the laggards of the liquid propellant family. They are plotted here because of their important contribution to space vehicle attitude and velocity control where a premium must be placed on precision rather than performance.

So much for the trends in performance parameters—now let's examine the role of the liquid rocket in space. First, why must we put up with liquid propellants when their solid cousins do not have the complexity nor the toxicity or volatility problems to contend with? There are many reasons why liquid propellant systems are destined to play a predominant role in space. The most significant are:

1. The highest specific impulse is attainable opening up many new facets of space exploration.

2. Long-duration firings are attainable, thus minimizing staging and acceleration loads.

3. "In flight" throttling and restarting can be accomplished "on command."

4. The extremely low temperatures of space can be tolerated—even to the point of allowing propellants to freeze during coast or storage periods and thawing prior to reuse.

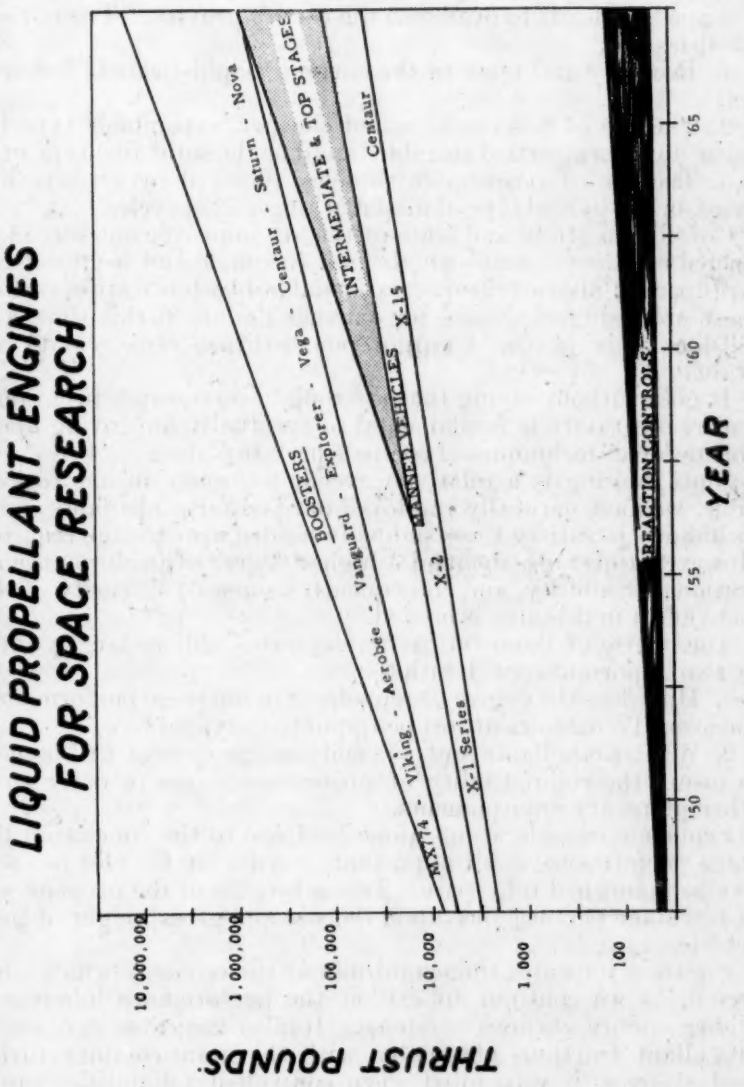
5. Lowest structural weights (or high propellant fractions) can be achieved by the turbopump feed system.

6. Safety, commensurate with human payloads, can be designed into the liquid systems, greatly enhancing the possibilities of survival when reliability falls short of 100 percent.

Now let us examine how these inherent features of the liquid propulsion systems contribute to astronautics and space exploration. Their applications lie in four distinct types of propulsion systems, all of which are vital to space vehicles. These are boosters, intermediate and top stages, manned vehicles or stages, and reaction controls.

Figure 3 illustrates the trends in terms of thrust size for each of these types of systems over a 20-year period; again, an attempt has been made to forecast the not too distinct future requirements. With this chart as a reference, I would like to devote the remainder of this paper to a discussion of the present and future needs and requirements in each of these four categories.

FIGURE 3


THRUST TRENDS
LIQUID PROPELLANT ENGINES
FOR SPACE RESEARCH
THRUST POUNDS
10,000,000
1,000,000
100,000
10,000
1,000
100
'50
'55
'60
'65
YEAR
BOOSTERS
Explorer - Vanguard - Aerobee - Viking - MX774 - Vega - Centaur - Saturn - Nova
INTERMEDIATE & TOP STAGES
Centaur
MANNED VEHICLES
X-15
X-2
X-1 Series
REACTION CONTROLS

Mr. THATCHER. First let's talk for a minute about boosters. Figure 3 indicates that booster thrust ratings in the 1 to 10 million pound class must be available to support payloads commensurate with manned space exploration. There is little doubt that this represents the largest present and future investment of the four propulsion categories. For this reason we must continually search for the most economical method of providing this tremendous impulse to our satellite and "escape" payloads to overcome the earth's gravity. The obvious possibilities are:

1. Recovery and reuse of the current "sophisticated" booster hardware.
2. The use of less complex and cheaper, expendable type boosters using a gas pressurized storable liquid or the solid fuel type of rocket.
3. The use of recoverable vehicles, powered by air-breathing engines, or the hybrid type of air-breathing-rocket cycles.

Continuous study and state-of-the-art improvement should be conducted on those systems which show economic and technical promise. Approach 2 above (cheaper expendable boosters) appears to be the most promising candidate for expanded effort at this time, and propulsion units in the 1-million-pound-thrust class should now be evaluated.

It goes without saying that a strong basic research program on the nature of gravity is fundamental to eventually improving upon these "brute force" techniques of escape from our planet.

Since staging is a relatively recent technique in our rocket timetable, we have naturally employed our booster propellants and design techniques to satisfy those suddenly needed upper stage requirements. However, top stages demand a higher degree of performance and operational flexibility, and consequently increased intensity of development effort in this area is needed.

The course of these future developments will be largely influenced by two important considerations:

1. How does the degree of refinement in top stage performance affect the overall economics of cost per pound of payload?
2. What propellants and/or conditioning devices will be necessary to insure the compatibility of propulsion stages in outer space and other planetary environments.

Economic considerations alone lead one to the conclusion that top stage performance is all important in reducing the cost per pound of payload launched into space. This is because of the pronounced effect of top stage performance upon the size and gross weight of the entire vehicle.

Figure 4 indicates the magnitude of the economy which can be effected, as we continue to exploit the performance inherent in our higher energy chemical systems. It also indicates that the higher propellant fractions obtainable with the more complex turbopump feed systems, is warranted when equivalent reliabilities can be obtained.

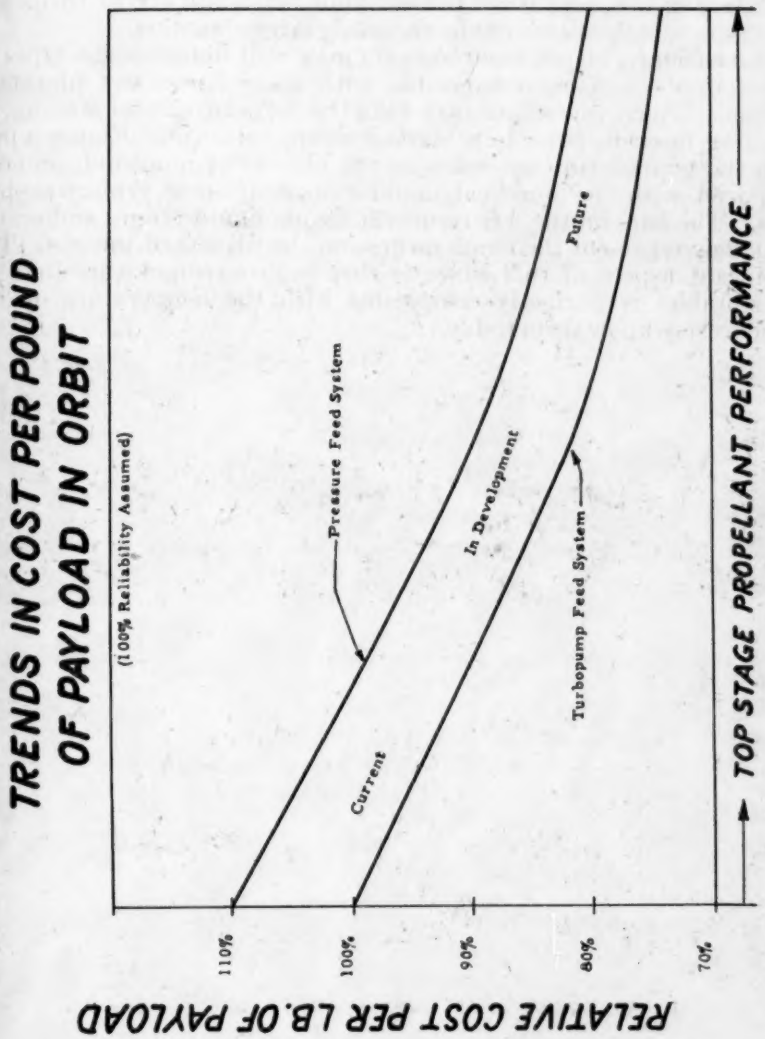

TRENDS IN COST PER POUND OF PAYLOAD IN ORBIT
(100% Reliability Assumed)
Pressure Feed System
Current
In Development
Future
Turbopump Feed System
TOP STAGE PROPELLANT PERFORMANCE
RELATIVE COST PER LB. OF PAYLOAD
110%
100%
90%
80%
70%

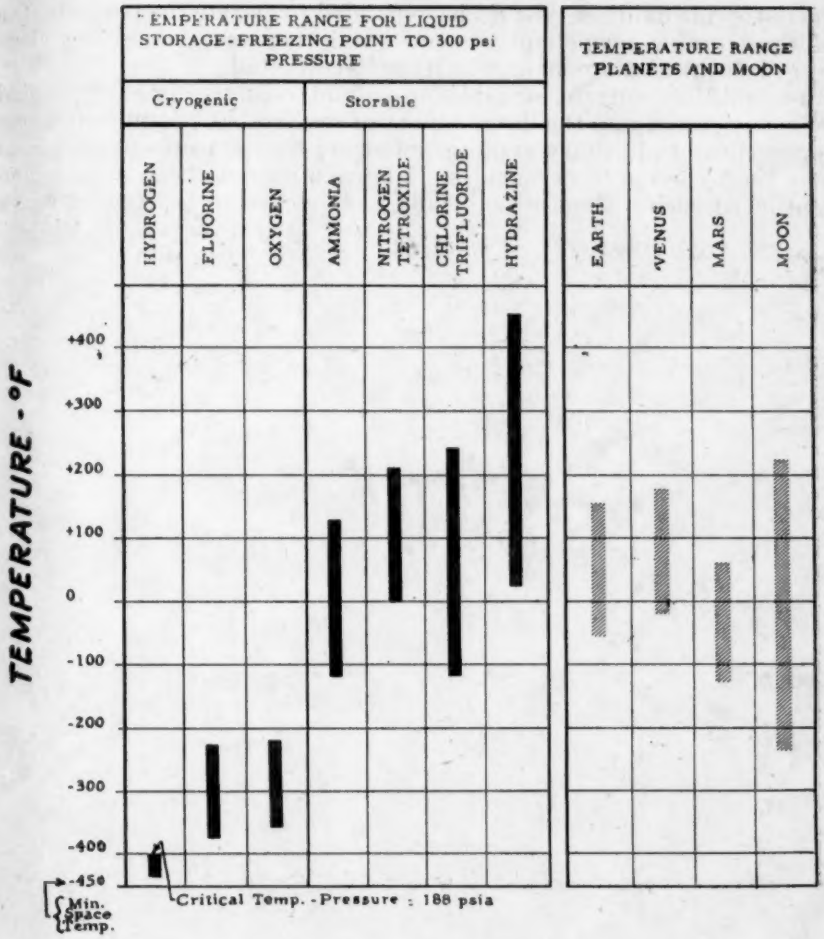
FIGURE 4

Mr. THATCHER. Our first recommendation on top stages is then: wherever reliability, environments and operational demands permit, "sophisticated" and high performance top stages will more than pay for themselves. This calls for an expansion of our current effort in this area. This effort should take the form of broadening our applied research base in the high energy cryogenic engine area, as well as immediately incorporating our present knowledge into higher thrust engines to be matched with the forthcoming larger boosters.

As mentioned above, environments may well influence the types of propellants which are compatible with outer space and planetary missions. Here, top stages may take the form of orbital staging, or refueling in orbit, prior to achieving escape velocities. Figure 5 presents the temperature extremes on the planets of immediate interest compared with the practical liquid ranges of some typical propellants. The bars on the left represent usable liquid ranges and on the right they represent the temperatures on the planets of interest. The significant aspect of this curve is that higher temperature limit of the storables is perfectly compatible with the temperature on the planets as we know them today.

FIGURE 5

COMPARISON OF PROPELLANT STORAGE CAPABILITIES AND PLANET SURFACE TEMPERATURES

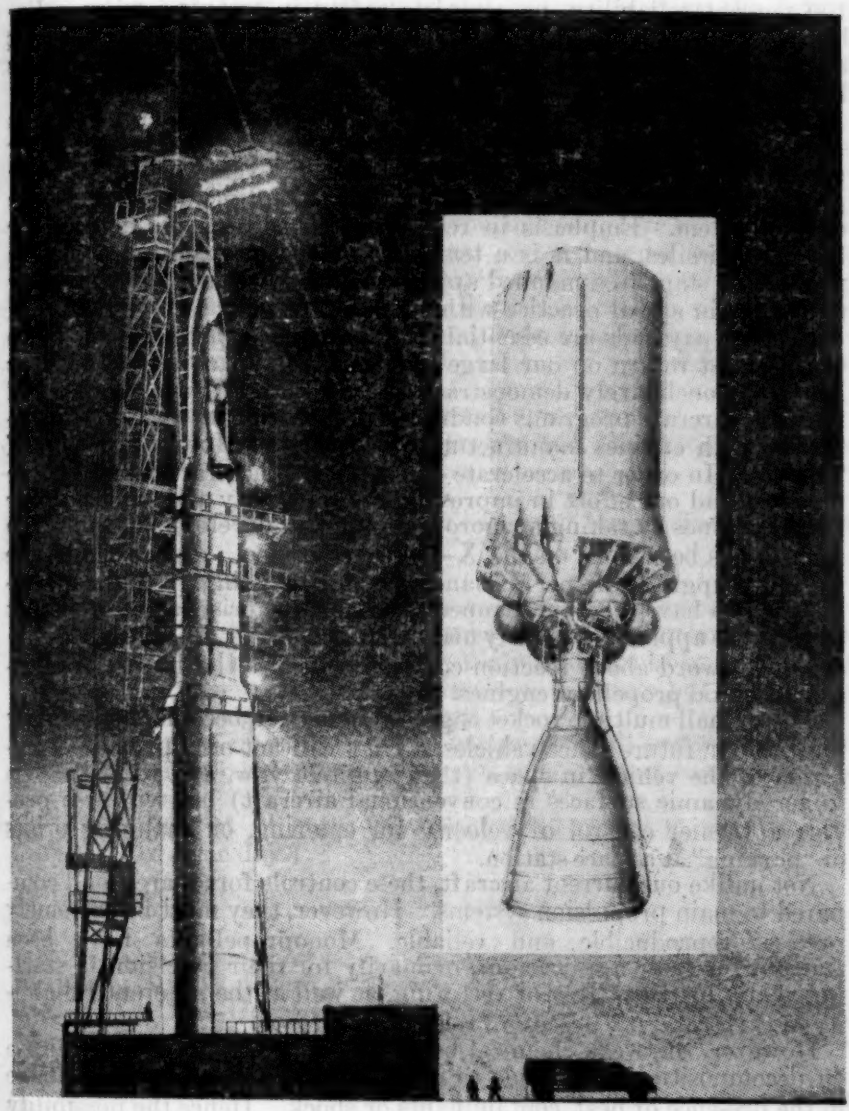


Mr. THATCHER. Unlike water, most propellants contract on freezing. Therefore, the lower temperature limit is of little significance when long coast periods in space or stowage of propellants on planets or space stations are considered, that is, we can allow the propellants to freeze.

The upper temperature limits of the cryogenic systems should not limit their use in outer space with proper radiation shielding; however, stowage on the planets appears to require refrigeration. Hence, the so-called "storable" propellants may well find important applications where storage, refueling, or restarting is necessary from orbiting space stations or on the moon or planets themselves. Our second recommendation under the category of top stages is then as follows: chemical research directed toward the synthesis of higher performance storable oxidizers should be expanded to elevate the performance of the storable propellant systems—and there are promising theoretical chemical compounds which can be exploited.

In addition, current storable propellant rocket technology should be incorporated into the development of restartable, propulsion stages for lunar and planetary exploration where temperature environments may limit the use of cryogenics. Figure 6 represents an artist's conception of such a stage which could be launched in less than 2 years.

FIGURE 6



Mr. THATCHER. The next category which I would like to speak about is manned vehicles.

This term applies to any vehicle or final stage where man is part of the payload. The presence of man has two significant influences upon the propulsion system which differentiate it from the unmanned type. First, he usually demands more controls such as thrust level, on-off, and an idling or check-out phase. Second, he demands either 100 percent reliability, or complete safety in escaping when reliability falls short of 100 percent. Experience has demonstrated that the reliability of a complex machine such as a space vehicle is always less than 100 percent.

Hence, it is imperative that we design our final manned propulsion stages in such a way that malfunctions will not destroy the vehicle or pilot, but will permit him to either return the vehicle to its base or provide him with sufficient warning or "safe time" to actuate his escape system. Emphasis in recent years has been on engines for ballistic missiles, and it is a tempting prospect to convert a missile propulsion stage to a manned application. However, this is not easy to achieve in actual practice without sacrificing our safety standards.

Manned payloads are essential to fully explore space and to obtain the greatest return on our large investment in space vehicles. This has been conclusively demonstrated in the high altitude, high speed research aircraft programs conducted in recent years by NASA, primarily with engines manufactured by Reaction Motors Division of Thiokol. In order to accelerate our manned spacecraft capability we must expand our effort in improving the reliability and safety of our rocket engines by taking a rigorous design and development approach such as has been done on the X–15 rocket engine. At the same time we must upgrade in performance the few existing propulsion systems which have inherent manned safety characteristics, in order that they can be applicable to early manned flights.

Now, a word about reaction controls, which is the fourth application of liquid propellant engines.

These small multiple rocket engine systems will become increasingly vital to our future space vehicles. They will not only provide orientation of the vehicle in space (that is, pitch, yaw, and roll—analogs to aerodynamic surfaces in conventional aircraft) but will also provide a vernier control of velocity for entering, or changing orbits or "parking" at a space station.

Not unlike our current aircraft, these controls forces are small compared to main propulsion systems. However, they must be extremely precise, reproducible and reliable. Monopropellants have been favored for these applications, primarily for their precision in starting, stopping, throttling or vectoring, as well as the inherent reliability of their catalytic process of releasing energy.

However, the weak chemical bond which allows the energy release on decomposition, also tends to make most of these liquids unstable in the presence of heat, contaminants or shock. Hence the possibility of synthesizing a higher performance monopropellant, which has an acceptable stability level for space environments and use cycles, seems somewhat remote. We recommend immediate use of available proven low performance monopropellants such as hydrogen peroxide.

However, we do believe that with a moderate improvement, present small storable bipropellant systems can provide comparable precision and reliability with considerably higher performance. Such an investment in our opinion will be more fruitful than attempting to "tame" some of the potentially higher performance monopropellants.

In conclusion, I realize that the above recommendations seem somewhat detailed to anyone not intimately associated with the propulsion field. However, they are fundamental in implementing the future course which we in Thiokol feel the space program should follow. Our major policy recommendations in this regard are as follows:

1. In order to reduce our high cost of launching payloads into space we must improve the performance of our top stages and simplify or recover our booster stages.

2. We must gear our program to the launching of men into space in order to effect reliable and scientifically fruitful missions.

3. In order to effectively "escape" from our planet we must either develop our orbital refueling techniques or even larger boosters than presently contemplated, depending upon the relative cost of sending large payloads into space missions. We feel it has been a great privilege to appear before the Science and Astronautics Committee with our views on rocket propulsion. I thank you very much for your kind attention.

The CHAIRMAN. Thank you very much, sir.

Let me ask you this, Mr. Thatcher, you and Dr. Ritchey, can you be here this afternoon.

Mr. THATCHER. Surely.

The CHAIRMAN. What about Mr. Young and Mr. Hoffman, can you be here?

Mr. YOUNG. Yes, sir.

The CHAIRMAN. We have had an opportunity of questioning Mr. Kimball, so it won't be necessary, unless there are further questions, for him to be back this afternoon. We would like to have you back at 2:30. We have to adjourn now because we have a bill on the floor of the House coming up the first thing.

But if there is no objection, the committee will recess until 2:30. Have your questions ready and we will then proceed to question the witnesses.

(Whereupon, at 12 noon, the committee recessed to reconvene at 2:30 p.m. the same day.)

AFTERNOON SESSION

The committee met at 2:40 p.m. in room 3214, New House Office Building, Hon. B. F. Sisk presiding.

Mr. SISK. The House Committee on Science and Astronautics will come to order. It is my understanding that Mr. Robert B. Young still has a statement to be made.

So, if Mr. Young will take his place at the witness table, we will be glad to hear that statement.

Mr. YOUNG. Mr. Chairman, I do not have a prepared statement. Mr. Kimball gave the statement this morning for the company, and I am here to answer any questions that may be put to me as representative of Aerojet.

Mr. SISK. Then I believe we will have Mr. Hoffman, Mr. Young, Dr. Ritchey, and Mr. Thatcher; if all of you gentlemen will make yourselves available there in the front row for questions, we will proceed.

I might say that the chairman of the committee, the gentleman from Louisiana, Mr. Brooks, will be along very shortly, but he was detained momentarily on the floor to get a little bill through over there. So he asked me to proceed here to try to cover the territory.

The Chair will recognize the gentleman from Pennsylvania, Mr. Fulton, for such questions as he has to direct to the witnesses.

Mr. FULTON. I would like to ask as to the various methods, types of propellants: Are we going fast enough on each type in research and development compared to the others? Are we lagging in any particular type of propellant development or should we put more emphasis on one type rather than another?

Dr. RITCHEY. I will start this off. Perhaps someone else will have comments when I finish.

Our propellant development work has up to now been pointed primarily towards systems application. I would believe that there could be a lot done, both in the liquid field and also the solid field, to explore the potentials of higher energy materials. Actually, we are still operating on compounds that were known as long as 50 years ago.

There has been very little done, or let's say not anywhere near enough done, to explore the potential of newer chemical compounds.

Mr. FULTON. I have had a resolution prepared that I have not put in yet to go into basic research as distinguished from applied research in the fuel and propellant field generally, and maybe make a full survey of the field and see what we can do on basic research. Would you favor such a program?

Dr. RITCHEY. I would indeed. I feel that there is not anywhere near enough being done along these lines. We have been very deficient in the money that has really been earmarked for basic research in the past.

Mr. FULTON. Would you feel that that study should be under any particular grouping, like, let's say, the National Science Foundation? Or should it be parceled out to universities or how would you go about it?

Dr. RITCHEY. That is a rather sizable question. Of course there is, for the first time, a rather sizable amount of money under the ARPA that is going out for certain phases of work in this field.

Mr. FULTON. Would you then combine ARPA, NASA and the National Science Foundation possibly in such a study? Would you combine the three agencies into some sort of a joint study of propellants and fuels in order to get basic research done which is really on a broader base and pretty expensive for any particular company to do?

Dr. RITCHEY. My own feeling is that there was a fairly adequate structure already established before these changes took place. This structure was administered under the three branches of the services in their own laboratories, and though the contractors which they had under their cognizance, and also through the research organizations they had, for example the ONR and OOR and the Air Force's OSR.

Mr. FULTON. But of course that has been changed so there is no use trying to go back and unscramble the hash. I am asking with what we have now, how would you make such a study of basic research in fuel and propellants?

Dr. RITCHEY. Frankly, I don't know.

Mr. FULTON. Do any of you other gentlemen have any suggestions, and if you do want to put them in the record later, I am interested very deeply.

Mr. HOFFMAN. These various organizations are still in existence and can and still do put out this sort of research contract. I might mention here that actually the basic research usually doesn't involve enormous amounts of money. In this area we shouldn't be concerned about duplication.

As a matter of fact, I think it is desirable while you are still in the basic research stage, developing new fuels and propellants. As a matter of fact, I believe a gentleman on this committee has a bill prepared advocating as far as industry would be concerned, at least—well, it would hold for universities as well—that a certain percentage of the value of contracts be allocated and applied to basic research. I think this sort of bill, if passed and applied, would be helpful. So then all of the existing and future contracts would automatically have built into them basic research funds.

Mr. FULTON. But the trouble is, unless you justify your basic research in each case, you get pretty much that. You just have a spare pocket of money that you can use without any particular watchdog on it. I would oppose any particular percentage being taken right across the board.

Mr. HOFFMAN. The percentage would be permissible and you would monitor it at the end of the year. Of course, one of the basic problems about basic research is that if it is basic when you start in on it, you don't know exactly where you are going to end up. And as was mentioned previously this morning, the things that you find are not practical are part of the job and are worthwhile, and to a degree at least, this money is as well spent as when you end up with something that is usable.

In other words, you have to toss out in basic research perhaps a good percentage of what you might have hoped to gain when you start out. You never gain all of it.

Mr. FULTON. My proposal is really aimed at making a team possible—NASA, ARPA, and the National Science Foundation—to go into the fuel field extensively and make a survey or a canvass to see if fuels, other than just the ones we are using, can't be used.

My point is to maybe get a basic study going, that we would get some money in the budget for basic research as distinguished from applied research. What do you think of that?

Dr. RITCHEY. The ARPA approach to this thing as a matter of principle, is fundamentally sound. As I see it, they took the view that the people who are in the business already were too inhibited by what they knew couldn't be done. So a certain percentage of this budget—how much I am not sure—I would say roughly half of it at least, went for an absolutely new approach in this field. From a research standpoint, I don't think anyone who has administered research can quarrel with this kind of a concept.

However, it is my own experience—and I would like to ask the people from the other companies if their experiences confirm ours—our own research budget in the rocket business has not increased one iota. In fact, it has actually decreased to some extent since this new system was set up.

I believe that this is basically wrong, if not from the standpoint of originality of ideas, at least from the standpoint of motivation, because those of us who are in this business, and make our living by making better rockets, certainly have a very strong motivation to do some very effective research in this field.

Mr. FULTON. May I hear from the other gentlemen who haven't spoken, and we are through. This is on the problem of a basic research study in the fuel and propellant field, missiles, rockets, and allied programs.

Dr. RITCHEY. As I understand, you are asking us if the research picture has improved any under the new setup?

Mr. FULTON. I am asking you, should we not have a study made, on a basic research basis, of fuel and propellants, pulling together various Government agencies to do it and maybe bringing in business as well, and look at the whole field on a general survey. Would you favor that?

Mr. YOUNG. Yes, I would say that we would favor this. This is something that in the liquid rocket field——

Mr. FULTON. Would you identify yourself each time?

Mr. YOUNG. I am Robert Young of Aerojet. In the liquid rocket field we have been hampered by lack of propellants as we call them, having to use what we have. The chemical industry has not come up with anything new, and such a program needs to be undertaken just as it has been in the solid propellant field.

As to the administration of it, that is not for industry to say. Certainly the chemical industry should participate because they have the basic capability, having developed other fuels for other purposes, and how it was administered by the Government can be decided by other than we.

But certainly within the framework of the agencies that now exist, this can be done.

Mr. FULTON. You don't have the money, do you, to go into the theories of the change in basic structure of molecules or atoms or the building up of different cellular structures. You don't have that, do you?

Mr. YOUNG. No, sir, and this is what should be undertaken—the investigation of the synthesis of new compounds, if you will, that will go as liquid propellants. Perhaps nothing will come of it, but at least it should be explored by people and groups that are competent in this field.

Mr. FULTON. I note for the interest of the chairman from Louisiana that I have in mind possibly synthesizing oil into a different molecular structure and coming up with maybe a different type of a fuel. Would that not interest the chairman?

The CHAIRMAN. We have plenty of oil and surplus oil. We would certainly contribute it to the program.

Mr. FULTON. And coming from a coal district in Pittsburgh——

Mr. YOUNG. Let's not overlook oxidizers too, Mr. Fulton.

Mr. FULTON. Could we ask you, then, on these new mineral and chemical fuels, say on boron, do you have any money or any room in your budget for basic research on that?

Mr. YOUNG. Not in direct connection with the application to rockets, although the boron fuels have been investigated mainly in connection with air-breathing engines.

Mr. FULTON. But I am really taking you one step further and saying, have you tried these things that have had other applications, instead of in oil and in coal, now to pick up boron, say, have you had the money to do the transposition into the rocket and missilery field?

Mr. YOUNG. We haven't had the money, and I am not sure that there is a payoff in that particular instance. We would like to see the element fluorine compounded or presented, formulated in a different form so it is more usable, because it represents a very high energy potential. But the element fluorine is expensive and hard to handle, as you know. We would be interested in synthesized fluorine compounds which are more readily available, easy to handle.

Mr. FULTON. Would cesium research be advantageous at this time or not?

Mr. YOUNG. I beg your pardon?

Mr. FULTON. Cesium research.

Mr. YOUNG. Not to my knowledge. I don't know what these gentlemen would say.

Mr. HOFFMAN. I think we would all agree as liquid rocket people that one improvement would be to do with liquid propellants the same job researchwise that has recently been done on solids—that is, to get the chemical industry working on the propellant, per se.

I belive we would all feel, too, that we could do more work on the known propellants in research in applying them to small rocket engines to check out their performance and possible problems.

Mr. FULTON. So if we would look at the overall field, without talking about these particular compartments between solid and liquid, we might get a better approach out of it, especially if we will recanvass the applications we have already had and follow out some of the projects that nobody—when they have made a turn of an angle they haven't gone ahead and done the further exploration that might be done on many old-type fuels. Is that not the case?

Dr. RITCHEY. If you will put that in the form of a motion, I will be glad to second it.

Mr. FULTON. Thank you. I appreciate it.

Dr. RITCHEY. Because really what we need to do is have exploratory work in the realm of new chemical compounds which could potentially have a tremendous payoff. Really there is no fundamental difference, looking at the laws of nature, in the long run, between solids and liquids. It is a matter of unlocking the laws of nature and finding how to put our best fuel combinations together.

Mr. FULTON. I am glad to hear you say that, because obviously you change both of them to gas at the time of use, whether it is a solid or liquid. So it is just your source and your container that is the difference, possibly.

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Would you then, all four of you, favor some sort of a basic research on fuels to get a field survey of current fuels resources and their possible application to missile and rocket fields?

Mr. HOFFMAN. That, sir, has been done. In fact I think the surveys have been done too much. We could have another one, but the real thing is to proceed with the basic research.

Mr. FULTON. I would say to you that I think it has been done a good bit, from some little experience I have had, in compartments. When I get off the liquid fuels, then one of you here says "Well, that is out of my field." That would mean that we may not have had the interlocking balances worked out.

For example, could I say to the gentleman from Aerojet, have you worked with hydrogen?

Mr. YOUNG. Yes, sir.

Mr. FULTON. Do you consider that a liquid fuel?

Mr. YOUNG. Yes, we do.

Mr. FULTON. Have you worked with this fuel, Arcia?

Mr. YOUNG. I do not recognize it.

Mr. FULTON. Or Phillips petroleum type.

Mr. HOFFMAN. That is a a solid fuel.

Mr. YOUNG. That is beyond my field.

Mr. FULTON. Don't tell him. I am trying to show the liquid people don't know the solids. You are helping me because I am saying that as soon as they get out of a narrow field, they don't know what the fuels are.

Mr. YOUNG. But the chemists do.

Mr. FULTON. The point of my questioning is to show that possibly we are compartmentizing too much in our science and we should get an overall view and see what fuels we presently have, or by change of synthesis and molecular structure we can turn into something new by a combination and put them into the missile and rocketry field.

Thank you very much.

The CHAIRMAN. Mr. Anfuso, any further questions?

Mr. ANFUSO. I will ask this question either of Mr. Hoffman or Mr. Thatcher or Mr. Young. What are the proper places of conventional and exotic chemical fuels? Should we look forward to using exotics exclusively, or are there economic and technical reasons for sticking to conventional fuels for many purposes?

Mr. HOFFMAN. I will take that, if you wish. On the charts, I mentioned that since performance is not of extreme importance in the first stage, we envision that conventional propellants would be used there because of cost consideration.

You will recall that I mentioned I included storables, for instance, liquids as being in that same category.

So here within that definition of conventional propellants, I would envision that we use conventional propellants of intermediate performance and low or modest cost.

As you go to the other extreme on the final stage—this was emphasized—that here performance is so important that it becomes almost mandatory to use the high energy propellants. The only cases you wouldn't use them would be if for some reason they wouldn't be applicable to storage under space conditions for long periods of time.

Mr. ANFUSO. You would use strictly conventional propellants then for the first stages, and then you would go to——

Mr. HOFFMAN. High energy for the upper stages, and in between you would probably, in certain cases, use one and in certain cases, the other, but more likely high energy propellants for intermediate stages as well.

The CHAIRMAN. Mr. Karth.

Mr. KARTH. Mr. Chairman, I can't help but feel I have heard conflicting testimony today. It seems to me Mr. Kimball said, when questioned about the cost of the fuels—that is, solids versus liquids—that he said the two were fairly comparable, that there wasn't a great difference because when you use liquid fuels, your instrumentation or your hardware was so much more expensive that it really balanced off the excessive cost for the solid fuels.

Is this a fact or isn't it?

Mr. HOFFMAN. What he said was true. It has been misinterpreted. I might try.

Speaking of a complete engine, let's say a complete engine costs a dollar. In the case of the liquid engine, the hardware would be 99 cents. The remaining cost would be this 1- and 2-cent-per-pound propellant that you put in the tanks.

In the case of the solid engine, on the other hand, the hardware, relatively simple today, will become more complicated going into big missiles; but nevertheless the hardware will be a smaller percentage of this dollar. And the fuel in place will be a large percentage of that dollar.

So perhaps in this $1, hypothetical, engine, in the case of the solid rocket it would be 90 cents for the propellant cast in place, and 10 cents for the hardware.

Mr. KARTH. So that I don't get confused all over again, let me ask you the question in this manner. A missile with about the same amount of thrust that is propelled by a solid propellant, with the same amount of thrust as a missile that is propelled by a liquid propellant: What is the difference in cost between those two vehicles?

Mr. HOFFMAN. My personal opinion would be that the cost would be roughly comparable.

Mr. KARTH. Then you agree in substance with what Mr. Kimball said. Is that right?

Mr. HOFFMAN. Oh, yes. And for a one-shot missile, you pay your money and pretty much take your choice. There will be other characteristics that decide which you want to use. However, should you want to get into missiles where you can use them over and over, for example, the recovered one that you mentioned, here the liquid missile will pay off because you use it over and over again.

Mr. KARTH. If you recover it.

Mr. HOFFMAN. If you recover it. But for single-shot, no recovery, I believe overall——

Mr. KARTH. It is clear to me now in so far as the cost of the two propellants is concerned. I was becoming a little confused because I understood you to keep saying you were using liquid fuels and you were putting a great deal more emphasis on them because they were so much cheaper.

Mr. ANFUSO. Let me ask you this. All of you gentlemen are interested in liquid rockets. I assume that you are interested in liquid stocks, too, are you not?

Mr. HOFFMAN. In liquid what?

Mr. ANFUSO. In liquid stocks.

Mr. HOFFMAN. I can't speak for the rest of the gentlemen, but I personally am not. OK, I am; I own some oil stock. So to that extent I am.

Mr. ANFUSO. All of you, then, are familiar with Thiokol. There is some relationship between Thiokol and your company, too, isn't there, Mr. Hoffman?

Mr. HOFFMAN. No, sir. Dr. Ritchey represents Thiokol. I represent Rocketdyne. I gather that what you may be getting at is the fact that North American and Phillips Petroleum are in partnership with a solid propellant rocket engine organization, Astrodyne, located in McGregor, Tex.

Mr. ANFUSO. Are your companies privately financed as well as publicly financed as a result of contracts with the Government?

Mr. HOFFMAN. The story I believe that Mr. Kimball gave this morning is rather typical of the industry.

Mr. ANFUSO. Typical of the industry?

Mr. HOFFMAN. Yes.

Mr. ANFUSO. In other words, the same thing that applied to Aerojet applies to Thiokol?

Mr. HOFFMAN. I believe so.

Mr. ANFUSO. Thiokol is largely dependent upon Government contracts. Isn't that right?

Mr. HOFFMAN. I defer to Dr. Ritchey.

Mr. ANFUSO. Is that true, Dr. Ritchey?

Dr. RITCHEY. In 1957 about 67 percent of our business was Government contracts, and in 1958 it would run closer to 85 percent of our business.

Mr. ANFUSO. Would you say that the same thing applies to you as applies to Aerojet, that whatever profits you make you turn back into the business for the purpose of development?

Dr. RITCHEY. What Mr. Kimball said this morning is essentially true of ourselves. We have put more money back into the business than we have ever taken back, in the form of a very small fee, which we have gotten for doing this work. We have not yet paid a cash dividend.

The ratio—I don't think Mr. Kimball gave any ratio—but from what I know about this company, I would say that the ratio between Government investment and private financing in the facilities is roughly the same also.

Mr. ANFUSO. You also say you have not paid a dividend yet. Is that correct?

Dr. RITCHEY. That is correct, a cash dividend.

Mr. ANFUSO. Can you gentlemen account for the sharp rise in Thiokol on the stock market?

Dr. RITCHEY. I was made a vice president about a year ago, and if I opened my mouth about the value of the stock, they would put me in jail—no matter what I say, I get put in jail for this. The

SEC has regulations about corporation officers making public statements of such nature.

Mr. FULTON. And the stock will do something, too.

Mr. ANFUSO. We don't want anybody to go to jail, but do you think this is a matter maybe for Congress to look into, overspeculation?

Dr. RITCHEY. I think that question is completely apart from our own business operations, and also this technological question that is connected with us—space technology.

Mr. ANFUSO. Do you think that the public is being duped in buying these stocks, thinking that the companies are making huge profits when, as matter of fact, they are not?

Dr. RITCHEY. I don't know who is duping them—if someone is. I certainly haven't seen any unrealistic estimates from the stockbrokers about the business potential or profits.

Mr. ANFUSO. Certainly the increases of the stock—that is, the values shown on paper—do not reflect the true value, do they?

Dr. RITCHEY. Isn't that usually true of—I believe that is usually true of what people consider a growth stock.

Mr. ANFUSO. I don't know whether it is usually true about other things, but it is true about Thiokol, isn't it?

Dr. RITCHEY. I think Aerojet has also had a comparable rise in price. So you might say it is——

Mr. ANFUSO. It is true of Aerojet, too. It is true about both.

Dr. RITCHEY. The ratio of price to earnings is something like 40, which has been true of chemical companies for years. They have been considered growth stocks. I believe that is the case. You are getting me in a field I am not qualified to talk about, you understand. I am only a rocket engineer. I believe the chemical companies have been considered growth stocks for years, and many other type companies are considered growth stocks. The ratio of about 40 times earnings is considered an equitable price for a growth stock. I think that is right. I think that is about what you will find ourselves selling for at the present time, and I think that is about what Aerojet is selling for.

Mr. ANFUSO. There is no rhyme or reason for either one of these stocks rising 40, 50 and 60 points within a short period when no profits are shown on the books and no dividends have been declared to the stockholders.

Mr. FULTON. Dr. Ritchey may be modest, but it may be a vote of confidence in his leadership as president since he has gone in.

Dr. RITCHEY. I am a vice president, sir.

Mr. ANFUSO. When did you go in, Doctor?

Dr. RITCHEY. May 1, 1958, I believe was the official date.

The CHAIRMAN. May I suggest this thought. You are dealing with space, aren't you? You expect them to go higher, don't you?

Mr. ANFUSO. You don't like the public to be fooled, though, Mr. Chairman.

Mr. BASS. Will you yield, Mr. Anfuso?

Mr. ANFUSO. I yield, Mr. Bass.

Mr. BASS. There are many other growth stocks that are selling 30 to 40 times earnings that are not in this field. I refer to IBM or

Polaroid or Haloid. All those glamour stocks are very high-priced, not just these.

The CHAIRMAN. Can you do this, sir. Give us a financial statement of your company to put in the record. That would apply to Thiokol and North American and Aerojet. If we could get that to put in the record, that would help some.

[The reports requested have been filed with the committee.]

Dr. RITCHEY. I believe Esso is on tomorrow. Do they get in the record, too?

The CHAIRMAN. We will put them in the record, too.

Mr. FULTON. Mr. Chairman, unless you put them all in, it is just a little bit hard to ask several to do it.

The CHAIRMAN. May I say this to the gentlemen, as far as the Chairman is concerned, this suggestion is not made in order to needle the companies in any way, but to shorten the hearings and give the information that the committee wants.

In the final analysis, I daresay that anybody on the committee can call up a stockbroker downtown and get a statement of your corporation. So there is nothing secret about it and there is no reason why it should be considered as in any way offensive.

Mr. FULTON. Will the chairman yield?

The CHAIRMAN. I would say the same thing tomorrow. We will ask Esso and the rest of them.

Mr. HOFFMAN. We are quite happy. They are public knowledge. They are printed.

The CHAIRMAN. Of course. There is nothing secret.

Dr. RITCHEY. I would like to make a statement if I may, please, in this regard, and also ask a question before this subject is tabled.

First off, I would like to say that both North American and ourselves are traded on the Big Board and we are subject to all the regulations of the Securities and Exchange Commission. Complete information is available and it is available to you. I would like to know what type you want. Is it the type that goes out in the annual report to the stockholders? Is that satisfactory?

The CHAIRMAN. I would think so; just a general statement. If the committee later on wants to probe the operations and organization and profits of the space propellant agencies, then that is a different proposition. I don't at the present time contemplate that or visualize it. I think we have a great job to do, and that is to get ahead in this space field. I don't think we are going to do it by tearing down what agencies we have.

Mr. FULTON. Will the gentleman yield?

The CHAIRMAN. I yield.

Mr. FULTON. Could we show in the record, then, affirmatively, that these statements were put in for the information and the broadening of the knowledge of the members of the committee and for no other purpose?

The CHAIRMAN. All of the hearings are for the same purpose.

Mr. ANFUSO. That was the only purpose of my asking the question.

The CHAIRMAN. Mr. Teague.

Mr. TEAGUE. Mr. Hoffman, if you had absolute power in the engine field, what would you do differently from the way we are doing it now?

Mr. HOFFMAN. If I had absolute power——

Mr. TEAGUE. Absolute power; money wasn't a factor.

Mr. HOFFMAN. In the missile and engine field, in the defense effort, I would put more money—which is a synonym for more effort—into the missile and powerplant effort.

Mr. TEAGUE. Would you let a contract for a 2-million-pound-thrust engine or a 3 million or a 10 million?

Mr. HOFFMAN. No; I would not today. Sufficient money has been put into these various jobs to do them. However, what the money assures you—the extra money, and it doesn't mean doubling or tripling—what the extra money does is that it insures, gives you greater insurance, of getting the job done on time, or getting it done on time and getting it done better.

It would mean a certain exploring of alternate methods of doing the job, some of which would not pay off and some of which would.

In a way—to sort of continue what I mentioned in a brief statement to Mr. Fulton—not only would I like to see some percentage permitted on basic research and encouraged, with a monitoring system; but I would like to see the same thing done in state-of-the-art development, which goes along with the basic research work.

Perhaps to clarify, we could go ahead, say, on a year's basis, taking, let us say, 10 items of improvement on an engine and handle it within the corporation that is in the business, as a complete job, rather than having to sell them piece by piece and maybe you sell only 80 percent of them. Yet to accomplish the job completely, you need this other 20 percent, too. I don't know whether I have made myself completely clear or not.

But on the one thing, my answer would be a definite "Yes." I would spend more money. On this I would like to make it clear that there is enough money to do a job; and I think for something as important to us as defense, we should have insurance and spend more money.

Mr. TEAGUE. We could be doing a better job. Is that what you are saying?

Mr. HOFFMAN. Yes, in my opinion.

Mr. TEAGUE. This morning I assumed that you belive there is no doubt that we will produce a 6-million-pound-thrust engine.

Mr. HOFFMAN. There is no doubt in my mind that we will.

Mr. TEAGUE. Is this contract, which we have let now, a step that we have to take? Do we have to go from a million and a half to 2 million, to 3 million, to four million? Or can we jump on up there some place? Should we have a contract out for something larger?

Mr. HOFFMAN. I don't believe so, sir. You see, we originally started with a 75,000-pound engine. That was quite a jump. We doubled that essentially to 150,000. When you go 10 times, that is quite an ambitious step in itself?

I don't think we are ready to go, say—you picked 10 million; that would be 1.5 million to 10 million, which is roughly 7 times. So we would be going 70 times where are today. I think that would be too fast.

Mr. TEAGUE. When will we know, and who will know, and who will make a decision to make the next big jump? And do we have

to sit and wait until this 1,500,000 is successful before we go to the next step?

Mr. HOFFMAN. No, we don't have to go that far. I hope we will have an opportunity in Friday's session where we are not hindered by classification to tell you where we are in the million-pound class. I would say in a matter of a year or so we will know whether we should go to a single engine of 10 million or 6 million.

I would like to emphasize again that once we have the million and a half pound engine, a six million or even a 10 million pound engine is perfectly feasible, a good practical engine by clustering.

As a matter of fact, this is the way we will get our first million and a half pound thrust vehicle, which I think is a very, very fine project that is underway. It is going to give us information about clustering existing engines, which later will be applied, when we have a million and a half pound engines to cluster.

Mr. MCDONOUGH. Just a point: As I understand what you are saying, you would spend more money, but you would spend more money making more of the same thing that you are making now.

Mr. TEAGUE. Refining it.

Mr. MCDONOUGH. Refining it and increasing the quantity. You hesitate to say that you would spend more money to increase the power of a thrust of an engine that you haven't already tested. You haven't tested the million, so you don't know whether the 6 million—you wouldn't go to the 6 million yet. But you would probably build more of the 1 million thrust engines than you are now building.

Is that what you mean?

Mr. HOFFMAN. I will try and clarify what I said. First of all, I would not start immediately to build a 3 million or 6 million pound single. I would spend more money to some degree. I would make more of the engines which shortly we will be making, the million-pounders, to have a little more freedom in hardware, so that as failures occurred, you could more quickly proceed with the program.

But more important than that, I would use the extra money to give us freedom to explore various roads. I mentioned on the chart how we have been able to simplify engines. You may recall the 1955 model that is flying today with 88 parts, whereas the one we are going into production on now—the one we have on the test stand—would have only 5.

We have been quite fortunate in that working with one of the services in the big missile program we were able to carry on an engine development concurrently—one that didn't have to go into missiles.

You see, first we had to get them in missiles. They had to fly. So we had to use things that we were quite sure would work to meet a date here. But off to one side we were carrying on this development work, exploring new areas, to come up later with a far simpler and better engine, which we will be putting out now this year, and a still better one next year using different control systems.

Mr. TEAGUE. Mr. Hoffman, do you think most people working in this field would agree with what you say?

Mr. HOFFMAN. I believe so, yes.

Mr. YOUNG. Could I make a comment, Mr. Teague?

Mr. TEAGUE. Yes.

Mr. YOUNG. We feel that the existing engines which we say are in the 200,000-pound-thrust class—this is per cylinder, if you will, or per barrel—represent what we have and their capability should be fully exploited. By that, I mean the capability for increasing their performance, increasing their reliability, and reducing their manufacturing costs so we can fully exploit the investment that this country has in the development of these engines, which hasn't come easy.

We have underway, as Mr. Hoffman indicates, in the country the development of the million and a half pound engine. We feel that the next step in thrust size should be ten million pounds, but that we do not have to start this step now because we have sufficient lead time, represented by the life of the existing engines, the useful life of the existing engines, plus the million and a half pound engine, singly and in clusters; that perhaps in 2 or 3 years we should start seriously considering what will be involved to effectively develop such an engine in the way of facilities and handling.

We probably will have to build the engine where it will be launched, produce the propellants at the same point, and put the whole thing together right at the launching site, because it will be so large that we will not be able to transport it.

But we have some time before we really have to start committing money other than just on studies—feasibility studies.

Mr. TEAGUE. You gentlemen, as men in this business and also American citizens, are convinced that this whole effort of ours is so coordinated that when the proper time comes to go to the 10 million pound thrust engine, we will, without just stumbling along until somebody finally makes a decision?

You think our whole effort is so coordinated that when the proper time is reached for that 10 million, we will do it?

Mr. YOUNG. My opinion is yes, the way the program is now laid out.

Mr. TEAGUE. Mr. Hoffman, do you understand my question?

Mr. HOFFMAN. The time isn't ready yet to start on a still bigger one.

Mr. TEAGUE. Do you think we will at the proper time know when to go for this ten million pound thrust engine?

Mr. HOFFMAN. We will know the proper time and we will, I think—speaking for the industry—be putting a lot of pressure on to get it going. I hope and expect that when that time comes there will be people in the various government agencies who will also recognize it and be able to get the money to do it.

Mr. TEAGUE. Must it come from a government agency, or do you people come back and make recommendations to the government agency?

Mr. HOFFMAN. We are continually making recommendations. On the big engines, we have been recommending it for a good many years.

Mr. SISK. I wanted to ask you the question, then, in view of the fact I understood you to say that the time is not right, let's say, to start construction of a ten million pound thrust engine——

Mr. HOFFMAN. Single engine.

Mr. SISK. That basically your reason is, because you don't have any use for a ten million pound thrust engine—that is, assuming that, miraculously one appeared today, you couldn't make any use of it. Is that right?

Mr. HOFFMAN. This is true, also that the missiles will have to be built and by the time we go from missiles that do require in the order of, say, 400,000 pounds thrust, in that neighborhood, it is quite a jump before they want ones of 10 million. The most ambitious projects now, I think, are in the order of perhaps 6 million.

Mr. SISK. I think I understand generally what you are getting at. But I was just thinking—in other words, what I understand you to be saying, is, your requirements and desire to construct larger and larger engines are dependent upon a need or a use for larger and larger engines, and the equipment and hardware and so forth that must go along, for meeting that need. And that therefore, today, we don't necessarily need one larger, let's say, than a 6 million pound thrust. I was simply asking you if that is what you were saying. Maybe I misunderstood what you were saying.

Mr. HOFFMAN. I think that would be essentially it.

Mr. SISK. I mean if we have a need for a 10-million-pound thrust, Mr. Hoffman, then I think we ought to be trying to build one.

Mr. HOFFMAN. I suppose you could say this: If we had a 10-million-pounder existing today that was reliable, I imagine they would use it. But we don't have, there is no need for it, and the missile people also have their limitations on the size of projects that they can tackle, too. And I think as a next step that they too would probably hesitate going from 400,000 to, say, 10 million all in one jump as a missile project. Before we put these great big ones up in space, there are certain necessary intermediate steps that need to be done on that, just as we feel on the engine work we wouldn't want to jump from a 10,000-pound engine to a million pounder.

Mr. SISK. Of course, the point that I had in mind, we have people come before our committee and discuss with us rather extensively their long-range thinking with reference to space stations, for example, and all the other things which certainly you are familiar with.

Certainly we are going to need engines with far higher thrusts than anything we have now, or that we even have on a drawing board, if we are going to construct in space a so-called space station. Isn't that true?

Mr. HOFFMAN. Yes.

Mr. SISK. Yet they come down here and show us designs of how it is going to be built and so on. I am not criticizing you people for doing that, but sometimes I just wonder how coordinated the whole program is, Mr. Hoffman. I am not being critical of what you are saying.

The CHAIRMAN. Let me ask a question, if I may.

Mr. SISK. Yes, Mr. Chairman.

The CHAIRMAN. In reference to the size of these engines: You envision a million-pound-thrust engine. You can see that ahead, can't you?

Mr. HOFFMAN. Oh, yes.

The CHAIRMAN. I say the largest project we have is a 6-million-pound-thrust engine. Is that right? I understood you to say that.

Mr. HOFFMAN. This is a reasonable requirement now. I suppose people might be talking about even more. This isn't necessarily the largest we will ever have, but I am sure the largest in the foreseeable future.

The CHAIRMAN. What I am getting at is this: In increasing the thrust and the power, you don't necessarily increase the size of the missile that carries the thrust, do you? You might increase your fuel. Since this is a hearing on propellants, have you given thought to increasing the power of the fuel, so that with the same engine you would get a greater efficiency out of it?

Mr. HOFFMAN. Yes, the high energy propellants would enter into the picture. And also I should add, as I mentioned this morning, we feel the nuclear rocket will come into the picture here. Actually as to the nuclear rocket, for modest jobs used in the first stage, chemical does it better. As you get into these more and more ambitious jobs, if we need 10, 20, or some other order of magnitude of millions of pounds of thrust, it is possible the nuclear might take over there.

The CHAIRMAN. Would you send the nuclear rocket aloft and then drop off the booster with the nuclear plant in it?

Mr. HOFFMAN. I think you would return a nuclear rocket. As you might gather, I am a very great advocate of recovering these expensive pieces of equipment.

The CHAIRMAN. When you get up to the second stage, then, would you leave that aloft with the nuclear power plant in it or would you bring that back?

Mr. HOFFMAN. Some final stage will have to come back because there will be a man or men in it. So the final stage eventually has to come back.

The CHAIRMAN. That would have nuclear propellant?

Mr. HOFFMAN. It could have, yes.

The CHAIRMAN. Would you get a greater power out of the nuclear rocket than you would out of the conventional fuels, solid or liquid propellant?

Mr. HOFFMAN. This will be discussed Wednesday, but I will just briefly state what I think was mentioned this morning, if I remember correctly.

There are two things you will notice, I hope, that become apparent before the week is over.

First, starting with chemical rockets, here your pounds of thrust per pound of propellant is modest. Let's pick a figure of 450 pounds of thrust per pound of propellant.

The thrust for every pound of engine weight, complete engine weight is very, very high in the order of a hundred or more pounds of thrust for every pound of engine weight. Now, as you go into the nuclear rocket, this situation reverses itself almost exactly, we believe. The efficiency about doubles—well, it triples.

Your pounds of thrust per pound of propellant will go to somewhere between 800 and perhaps 1,500 pounds of thrust per pound of propellant. The weight on the other hand goes in just the inverse ratio. So efficiency will go up three times and the weight will be three times as bad.

Finally, as you go to the extreme of ion engines, again using a nuclear source, the same thing continues. So as you get into space, using a nuclear source, either as a nuclear thermal rocket or as a nuclear ion rocket, you are getting just what you want—a piece of equipment that doesn't require filling stations in space for very, very long periods of time.

I think you might say in a rough way that what the nuclear power gives you is endurance. It is heavier.

The CHAIRMAN. But if you have your weight increased three times and your efficiency three times, would the one neutralize the other, the increased weight neutralize or offset the increased efficiency?

Mr. HOFFMAN. They do for certain applications. As I mentioned for first-stage boosts. You recall I mentioned efficiency as of less importance. As you have modest applications, the chemical job is better all around than the nuclear.

However, as you get into these very, very large jobs, requiring very, very large thrust, here is where the nuclear job starts to take over, and you do the job with fewer stages.

The CHAIRMAN. Coming to that, wouldn't we do a better job if we devoted more of our energies toward the research and development of power of propellants than to putting in so much thought on a huge rocket? You referred to the bill. It was a committee bill introduced which would authorize 10 percent additional to every contract for scientific development. That 10 percent would be devoted to basic research.

We would be in better shape if we did more of that and increased and developed new types of propellants, we will say nuclear is one. Perhaps chemically we could develop a much higher efficiency in propellants, and thereby cut down the weight of our rockets and still get the efficiency.

Mr. HOFFMAN. You still need the very large powers so you must go ahead with the larger engines. That is an axiom and I think all of the panel here will agree.

The CHAIRMAN. Would we be better off if we did devote more time to basic research in these contacts with these plants that have general development contracts?

Mr. HOFFMAN. We believe more work should be done in this area. So that there should be no misunderstanding there, I have given a chart this morning. Chemically about as far as you can go, unless there is some new kind of chemistry discovered, is somewhere in the order of this 500 seconds or 500 pounds of thrust per pound of propellant.

The CHAIRMAN. You mean physically it is not possible to increase that in chemistry?

Mr. HOFFMAN. Right.

The CHAIRMAN. You would have to develop some different type of propellant like nuclear or——

Mr. HOFFMAN. Then you go to the nuclear system, and here you triple, at least you have the potential of tripling, what you can do.

The CHAIRMAN. 1,500 pounds, I think you said.

Mr. HOFFMAN. Yes, 1,500 seconds, specific impulse, which is 1,500 pounds of thrust per pound of propellant.

The CHAIRMAN. Have you any hopes of developing any new types of propellants, other than the ones you have mentioned, which would offer greater efficiency with less weight?

Mr. HOFFMAN. I think the answer to that is no, for the nuclear job, the best propellant you can use is hydrogen. If you put something else in it, it would be for reasons other than performance, as far as any major magnitude is concerned, but for operating reasons. The

same statement, I think is sound as far as the chemical propellants are concerned.

Fluorine with hydrogen is right up at the top on the chemical scale. The research that would be done would be to make the fluorine-hydrogen combination handle more easily, and envisions additives to this that would push the performance up, but not twice. It would be some small percentage perhaps 5 or 10 percent.

The CHAIRMAN. Then you don't hold out much hope of increasing the types of propellants, even if we increase the amount we spend for basic research for propellants.

Mr. HOFFMAN. Yes; you would improve the characteristics of fluorine-hydrogen, for example, and you could possibly push another 10 percent, something in this order of magnitude. This is worth doing. You recall I mentioned how much you gain with improvements of efficiency. In the upper stages it is a lot.

The CHAIRMAN. To go beyond that, we would have to improve the rocket rather than the propellant. Is that right?

Mr. HOFFMAN. Yes. What you would do there, once you achieve the ultimate there, then you would go to nuclear, where you make the step of three times, and for the very final stages, to something like an ion plasma or similar engine where you make another order of magnitude jump and get up to specific impulses, I think, of 20,000.

The CHAIRMAN. How much?

Mr. HOFFMAN. 20,000. So you see, for the first jump in efficiency, you go from chemical, of let's say 500 seconds to 1,500 seconds nuclear an improvement of 3 to 1 in efficiency. In an ion engine, your next step would be from 1,500 to 15,000 or possibly 20,000, a step of 10 to 1 again. However, each time you do this the propellant gets heavier.

The CHAIRMAN. How far away are we from an ion engnie?

Mr. HOFFMAN. This depends upon how badly we want to push it. I would say at the very, very closest 5 years, and probably somewhere between 5 and 10 years.

The CHAIRMAN. Isn't that the ultimate propellant, as far as you see it now?

Mr. HOFFMAN. Only for the space application. I am sorry that I seem to be obtuse here, but it is not a simple problem. Let us take it in three steps, and this is indeed an oversimplification.

But for first, overcoming the gravity of the earth and getting out of the earth's atmosphere, chemical is almost as good as you can do, because of its high thrust-to-weight ratio and its good performance.

Then as you go on up, you can envision an improvement by using a nuclear thermal rocket, where now your performance goes up to somewhere between 800 and 1,500 seconds. The weight is quite large.

Then finally, way up in the upper end you have this missile out in airless space. There is no friction. A very, very small thrust over a long period of time will get you going very, very fast. You will be able to maneuver with very minute loads, as will be brought out Thursday. For these upper stage engines we are talking in the order of a pound of thrust.

We get this pound of thrust with practically no consumption of propellant, which is fine because there are no filling stations there. On the other hand, the engine is very, very heavy for this pound

of thrust you are getting. In fact, using conventional electrical sources you would have something like a small-city power plant. In the laboratories, ion engines are working with a fraction of a pound of thrust. The ion gun part of it is working. The real problem on the ion engine is to get an electrical system that is practical and doesn't weigh too much.

It will unquestionably have a nuclear source of energy, and at the start it will probably require turbines and rotating machinery for the conversion.

The CHAIRMAN. As I understand, then, you have ion engines now operating, but they are so small they are not adaptable to missiles because of the lack of a suitable electric system.

Mr. HOFFMAN. Breadboard, let's say, thrust chambers, not the complete engine. The complete engine is a big thing. They are operating today by taking the electric power out of the city power lines. The ion gun itself, a rather small gadget, weighs very little. But the principle—I think without question, it can be done. The big money and the big effort will be in electrical power to do the ionization and power the gun.

So as to the basic principles, we can say today that we can build an ion engine. An ion engine is worthless for a booster. It can't lift itself. An engine providing 1 pound of thrust will weigh thousands of pounds. But it is a fine engine if you can get it up into the air with big boosters, and then cruise around among the planets, or around Mars, or wherever you want to go.

So the distinction really is, to get out from the earth you need a very, very powerful engine, very light weight to lift these heavy weight, extremely efficient engines up into space. Then once they are in space, although they are heavy, they are there and it takes practically no propellant to operate them. So they can operate for a long period of time.

The CHAIRMAN. Mr. Fulton.

Mr. FULTON. The great gain of an ion engine, of course, is that it has continuous acceleration.

Mr. HOFFMAN. This is the way you would have to use it because a pound of thrust on a great big heavy thing means that it takes a long time for it to accelerate. It is rather like compound interest; you get a little bit every hour, and eventually you are going very, very fast.

Mr. FULTON. I think some of us have seen a laboratory model of an ion propulsion system working in a small vacuum. Could somebody bring one here to the committee for us to see, with the chairman's permission? I think other members would like to see it.

May I comment on this. When you have a Vanguard where maybe you have 140 seconds of thrust, or a moon shot maybe going 304 seconds of thrust, how much of the fuel is expended in either one of those type vehicles, say kerosene and lox, in the first 30,000 feet?

The point of my question is this. Why do we always start these missiles or rockets at sea level? Why don't we go to Mount Everest or Kinchinjunga, the third highest mountain in the world, next to it in Pakistan, and make some sort of a deal with them and maybe we don't have to have such big engines if we start them up at 30,000 feet, because to begin with, you must not only carry the

payload, but you have this whole pyramid of fuel that you are using starting them from a dead stop at sea level.

Mr. YOUNG. Could I comment on that?

Mr. FULTON. Yes.

Mr. YOUNG. Mr. Fulton, what you are talking about is eliminating atmospheric drag. That represents only a small portion of the total energy required to get something into orbit or out of the earth's gravitational field.

Mr. FULTON. Yes, but what proportion of your fuel do you use in the first 30,000 feet on these tremendous engines?

Mr. YOUNG. You use a fair portion of it. Starting from 30,000 feet you would still use a lot of it, and it is the velocity you are after, not where you are.

Let's say you started from Everest. When you were 30,000 feet from Everest—in other words, at 60,000 feet—you will have used the same proportion of fuel, roughly, and still be going the same velocity.

So you have only gained six miles, which is meaningless. It is the velocity that you are after, not where you are.

All you do is save a little bit of drag work, which isn't very much. You can almost ignore it.

Mr. FULTON. If it took, say, a thousand pounds to put a pound into orbit——

Mr. YOUNG. Yes, sir.

Mr. FULTON. Possibly if you reduced the distance to orbit, say, by 30,000 feet where the atmosphere is most dense, you would get a very great reduction in the ratio——

Mr. YOUNG. No, sir.

Mr. FULTON. Of fuel and the weight of the vehicle to the payload.

Mr. YOUNG. No, sir; I don't think so.

Dr. RITCHEY. May I comment, Mr. Fulton?

Mr. FULTON. Yes.

Dr. RITCHEY. I believe the misunderstanding here involves not only height but the neglect of the velocity that this missile has. When it passes 30,000 feet it not only has gained that altitude, which of course is important, but also at burnout it has a very sizable velocity which is even more important.

Velocity is where most of the fuel goes—into imparting velocity to the missile. Even after it burns out, it will go ahead and coast another hundred miles high, perhaps, before it starts to come back.

So really the energy content at that point that was put in the missile by burning the fuel is represented by the height it would coast after this and not just the altitude at burnout.

Mr. FULTON. Could I ask you, gentlemen—because you are interested in the propellant fields: Suppose you have a rocket or a missile and on the horizontal plane the thrust is the push forward, and the drag is the friction or the pullback; and on the vertical approach, that would be lift as against gravity.

You are talking about so many pounds of thrust and what it does. Suppose that the thrust equals the drag on a missile and the lift equals gravity. What is it doing?

Mr. YOUNG. You are standing still. It is in equilibrium.

Mr. FULTON. Where is it then? I was given that on a Navy lieutenant examination without any warning, to see if I could be promoted in the Reserve. Could you answer that for me quickly?

Mr. YOUNG. If it is in space it is floating.

Mr. HOFFMAN. If it is on the ground, it stays there.

Mr. YOUNG. Wherever it is, it stays unless it has velocity and then it coasts.

Mr. FULTON. I think if it is within the earth's gravitational system it must be moving in orbital, continuous unaccelerated flight. If it is outside the earth's gravity, it is in a single directional unaccelerated flight.

Mr. TEAGUE (presiding). Mr. Wolf would like to go to another meeting and would like to ask a question.

Mr. FULTON. Just a minute and I am through. What is the answer to it? I don't believe you could be Navy lieutenants.

Mr. YOUNG. Did I understand you to answer the question, Mr. Fulton?

Mr. FULTON. I answered it, but I wondered if you agreed with that.

Dr. RITCHEY. Yes, that special condition fits the definitions you have put up. However, there are many other conditions that also fit that definition.

Mr. FULTON. Could you name one of them?

Dr. RITCHEY. An airplane flying at constant altitude at constant velocity is one I believe would fit that. A satellite, a missile coasting through free space, or one that is passing the moon would also fit.

Mr. FULTON. Just in all good humor, it just couldn't be sitting on the ground, though, could it?

Dr. RITCHEY. It could be.

Mr. HOFFMAN. If it starts from the ground, that is where it would still be.

Mr. TEAGUE. Mr. Wolf.

Mr. WOLF. I notice that you commented that you were in favor of salvaging these first and second stages. I understand you build engines, but do you have any information to enlighten us on what is being done to salvage first and second-stage rockets?

Mr. HOFFMAN. There is a lot of thought in the missile industry now.

Mr. WOLF. I am speaking in terms of not thought, but money being spent and work being done.

Mr. HOFFMAN. There is none actually being built to my knowledge, although it is being studied. I think one will be built.

Mr. WOLF. As we get into more and more expensive clustered engines, are we being a little foolish in spending millions of dollars to blast these things off and then kick them off and just forget them? Wouldn't it be smart economic budgeting to spend, say, a percentage to create a means to recover them?

Mr. HOFFMAN. Yes, and I think this will come as a matter of course. Experiments will be made on recovery as a step following sending them off as now in nonrecoverable form.

Mr. YOUNG. May I comment on that? It is simply a matter of economics whether you recover a booster or not. You have to make the booster bigger to carry its own recovery devices, so that you have to fire more missiles or make the whole thing bigger.

Then it costs you a certain amount to recover it and a certain amount to recondition it, and until you pass the point where you are having a net gain, there is no point in trying to recover them.

Mr. WOLF. But we are talking in terms of a clustered rocket, a million pounds of thrust and things like that. We are talking in terms of an amount of money similar to the price of a battleship. We can afford to figure out a way, I would think, to at least attempt to recover. This is the answer we have always gotten on this question.

Mr. YOUNG. You still have to save money to do it.

Mr. WOLF. Someone suggested here this morning to use parachutes. Parachutes aren't that heavy.

Mr. HOFFMAN. A parachute won't give you a complete job.

Mr. YOUNG. You have to do more.

Mr. WOLF. Is any money being spent right now? This is what I would like to know.

Mr. HOFFMAN. I think so.

Mr. WOLF. Could you produce that? Could you tell me where we could get this information?

Mr. HOFFMAN. When you say any money, I would be very happy to talk about it on Friday. I think it would be more appropriate there than here.

Mr. WOLF. It is always we get into this question of whether or not it is classified whenever we want to know the answer to a question as vital as some of these are. It is a little frustrating, you see.

Mr. HOFFMAN. All I can say now, I think some is. I can tell you places to go. I would like to point this out, however. For a period of years this is going to be more expensive than throwing them away.

The reason I personally am so strong for recovery, I am convinced that it will eventually be done; and the earlier you start doing it, the quicker you will get it.

Mr. WOLF. I am with you.

Mr. HOFFMAN. But I will admit, first of all, for the first year—and it might be a period of 10 years—this will be more expensive than simply building the simple ones and throwing them away.

Twenty, thirty or forty or some number of years from now, this will be the way it will be done.

Mr. WOLF. I am not a stockholder of the company, but of course I do understand you want to build engines; and if they are gone, you can replace them. I understand this. But I would like to see someone seriously consider this thing.

Mr. HOFFMAN. I would like to say on this, along with that connection, we do work for companies—all of us are engineers basically—and really our interest is to build the best engines we know how and the best missiles and basically we are not thinking about trying to keep them nonrecoverable.

In fact, the contrary is true; particularly in the liquid engine business, we feel that this is an inherent virtue of a liquid engine.

We would like to see it capitalized. We are engine people, and I might say in all honesty for better than two years we have been promoting this for missile people. The missile people understandably, I think, have not been able to work on this. Everybody has been as busy as they possibly can be, getting existing missiles to work.

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I didn't have time to go through the history, but our history in the United States of big missiles and big engines was pretty short. As a matter of fact, there was no appreciable money, as we speak of it today, put into liquid rocket engines until about the middle of 1953.

So what we have accomplished today with substantial money is essentially within the last 5 or 6 years. Prior to that it was pretty much of a shoestring. This will come. And since you made that remark, I do want to emphasize that I am sure every one of these gentlemen sitting here with me—our interest is to insure the engines are in the best possible installation. I for one, and my organization, will be only too happy when the day comes that they are recoverable. What we would like to aim for, and see, is that they come back.

I have shown this ideal condition in the vertical position, ready for the launch, that you simply tighten up the pipes with a hydraulic and mechanical checkoff, refuel, and be on your way again. We would feel then we have done the job we would like to do eventually.

Mr. WOLF. For the record, would you say that if it were possible, you would like to see a supplemental appropriation that didn't deter from the money being spent for engines to do some real serious research today on recovery?

Mr. HOFFMAN. Yes.

Mr. BASS. Mr. Chairman?

The CHAIRMAN. Mr. Bass.

Mr. BASS. Mr. Hoffman, you told us a few minutes ago, I believe, that a vehicle in space, after it leaves the gravity of the earth, requires relatively little thrust to attain a great speed. You were talking in terms of a pound or two pounds.

My question is a little theoretical, but supposing a vehicle had a great deal of thrust, in the order of several hundred thousand pounds out in space. It would acquire fantastic speed very shortly. Is that correct?

Mr. HOFFMAN. There is a limit on speed, the speed of light.

Mr. BASS. That is what I am leading up to. Is there any limit?

Mr. HOFFMAN. The physicists tell us that the speed of light is a limit. I am rather unhappy to hear this because, if so, it is hard to imagine how we will get outside of our solar system.

Mr. BASS. Why is the speed of light a theoretical limit?

Mr. HOFFMAN. Dr. Ritchey, would you want to undertake that? I don't know how I could answer that one.

Dr. RITCHEY. I think Professor Einstein is the one who figured this out, almost all, I believe, with some help from the Lorentz-Fitzgerald relationships. It gets into very complicated matters, which are really beyond normal every-day experience and can only be described in mathematical equations.

Mr. BASS. Then it is impossible, according to Einstein, for us ever at any time to get out of our own solar system.

Dr. RITCHEY. He postulated this theory, and I think the theory has been pretty well proved; at least in the regions in which we can observe, it very definitely fits the facts of nature. If this theory can be extended to this maximum limitation on velocity or speed, then the speed of light is the limiting speed which we can ever attain.

Mr. BASS. The nearest star is several million light years away.

Dr. RITCHEY. If this is the fundamental limitation, and if the sum of human knowledge in this area never extends beyond the Einstein theory, what you say is true. It will never be within the reach of a human lifetime to travel to a star a thousand light years away, and get back and tell about it.

Mr. FULTON. Would the gentleman yield for a disagreement?

Mr. BASS. I will yield. I have a couple of more questions, but I will yield.

Mr. FULTON. On that point, suppose you are in a capsule going the speed of light and you throw a baseball forward 30 miles an hour. What happens to it?

Dr. RITCHEY. You can't throw the baseball forward 30 miles an hour if you are going at that speed. According to this theory, no matter how hard you throw the baseball, it goes a little bit faster than you are, but never goes quite as fast as the speed of light.

Mr. FULTON. It could only move backwards, then.

Mr. HOFFMAN. When you go that fast, things become flat.

The CHAIRMAN. There are no curves at that speed. Any further questions?

Mr. BASS. Yes. Getting down more to earth, Mr. Hoffman, you also told us a little while ago that you felt that the Government was not spending enough money in this field.

Primarily, as I recall your testimony, you said that particularly in the field of research and development that was the case. Am I correct?

Mr. HOFFMAN. Yes. The question really was, if I had supreme power, would I spend more, and I said yes.

Mr. BASS. Just spending more money isn't necessarily going to produce bigger results, is it?

Mr. HOFFMAN. Yes, that's true.

Mr. BASS. It is effort that counts, isn't it, not money?

Mr. HOFFMAN. Right.

Mr. BASS. We just have so many men, so many scientists, so many people, who can work in research and development. Just spending more money is not going to produce more results, is it?

Mr. HOFFMAN. We can spend more money and produce results.

Mr. BASS. Then you must be talking in terms of hiring more people, more scientists.

Mr. HOFFMAN. Actually as of now we could spend more money and produce results with essentially the same number of people.

Mr. BASS. How is that?

Mr. HOFFMAN. Well, some of them may disappear here over the next year or so.

Mr. BASS. You are talking in terms of raising their compensation, you mean?

Mr. HOFFMAN. No. I am talking in terms that a certain amount of the new work is not equivalent to the effort we are putting on in all the old jobs; so there could well be some lessening of the number of people now at work on engines.

Mr. BASS. We have X number of scientists, research men, engineers and so forth. If we double the amount of money that the Government is spending on research and development, where would that go—raising these men's salaries or hiring twice as many? And if so, where would they come from?

Mr. HOFFMAN. You may recall I was not speaking in terms of doubling. I said a reasonable amount.

Mr. BASS. A couple of hundred million dollars?

Mr. HOFFMAN. Ten or twenty percent would be a great deal in this area.

Mr. BASS. That would be $100 million more, maybe. Where would that money go?

Mr. HOFFMAN. I will speak of our own organization. It would go essentially for people that are going off the older jobs that now are in production, and putting them on new developments in the area that I have spoken of—state of the art. It would also be putting people to work in basic research in the chemical industry on new propellants.

Mr. BASS. Those people are already on the Government payroll, are they not?

Mr. HOFFMAN. Not in the chemical industry, I don't believe.

Mr. BASS. Who is paying them?

Mr. HOFFMAN. In the chemical industry?

Mr. BASS. Yes.

Mr. HOFFMAN. I guess we all are, buying gasoline. I think as far as the Government work is concerned, the chemical industry would probably be—I am guessing—I suppose certainly in the high 90 percent civilian work. I say I am guessing. Certainly it is not like our business, which is 100 percent Government work.

Mr. BASS. Spending X millions of dollars more in research and development means hiring more scientists in this field, does it not?

Mr. HOFFMAN. This depends on the organization. I say in our own case, on new work, the necessary scientists to do this research and development work are available. With inflow of new work some people will go out of the rocket engine business into—I don't know.

Mr. BASS. I just don't see where these new men would be coming from.

Mr. HOFFMAN. What I am trying to point out is that they all wouldn't necessarily be new. You see, each year you get an engine, your initial work is done. There is a transition from conception, design, and development, into production. So the people that started out with conceptional ideas and made drawings and did the new development work, they get out of jobs.

Unless we feed in enough new conceptional work, either they are, as you stated, wasted by going into purely production work, or else they disappear, because they want this kind of work, into maybe the machine tool industry, the automobile industry, or somewhere else. So by getting this new work you would keep your level of employment roughly stable.

The CHAIRMAN. I want to say at this point, I promised some of the members I would adjourn around 4 o'clock because the Governor of California has a reception for the California men and some of the others have to go elsewhere.

Are there many more questions? Do you have many more? We could ask them to come in tomorrow but I think we have five more witnesses tomorrow.

Mr. BASS. I will defer to your wishes.

The CHAIRMAN. I don't want to cut you short. I thought you were about finished.

Does anybody else have any questions?

Mr. Daddario?

Mr. DADDARIO. I have a couple, and I will limit them—just one question to Mr. Hoffman. Do you eliminate the nuclear power in the booster stage because of the radiation effect, or because it does not have in itself capacity to do that job at that stage?

Mr. HOFFMAN. Basically we feel that the first application of the nuclear rocket should be in the second stage, and the main reason would be for the reason that you enumerate, possible radiation hazard. And also the fact that by using it on upper stages, you can cut the weight of the plant down because you can go to shadow shielding rather than heavier shielding required on the ground.

Mr. DADDARIO. When we get to the stage where we somehow overcome the need of such heavy metals to protect against radiation, then we could perhaps use nuclear power in the initial stages?

Mr. HOFFMAN. And when we know more about what the exhaust products will be and things of that sort, it will come. Then you would use it for these very, very ambitious projects where we are talking 10, 20, or so millions of pounds of thrust.

Mr. DADDARIO. Dr. Ritchey, without getting too far into this because we don't have too much time, this morning in an offhand manner, you indicated that what you thought was indicated by some of the questions here, as being a criticism insofar as duplication and overlapping was concerned, was in fact really competition, that you needed competition in the technological development of the space business.

Dr. RITCHEY. I think competition is a very healthy thing.

Mr. DADDARIO. Who is going to determine if this is so? The Government is just going to scatter money around to all of these various people so that they can be in competition, so that their ideas can develop.

Who is going to decide when the experiment ceases and that somebody has achieved a result, so that the moneys then stop and are diverted into another area? Who is going to watch all of this?

Dr. RITCHEY. In a competitive system the customer always has the last word. I think, however——

Mr. DADDARIO. In a competitive system who has the last word?

Dr. RITCHEY. The customer always has the last word. The customer in this case is the Government.

Mr. DADDARIO. We have had cases, haven't we, where you have had duplication, where you have had the same type of vehicle developed to do the same type of job? You have had it in the Atlas, you have had it in the Jupiter, the Thor. In all of these fields. You have had it in the fields of the development of bombers during the war, where you have had one vehicle that could have done the job, and you find yourself with three or four.

If you follow your competitive theory, should you now stop at someplace where you reach the point in experiments that you know that that vehicle will do the job, get into production on that alone, and wouldn't you save money if you did so?

Dr. RITCHEY. The answer to that "saving money" question is a very intangible one. You never can say. You can always say that if everyone had done as well as he did under a competitive system; but if there hadn't been a competitive system, you might have saved money.

But I can bring up the same question here in respect to the analogy I used this morning. For example, take the oil industry. The pressure of competition has tended to make everyone in the petroleum industry do very well. They tended to cut costs, they tended to improve products, and consumer relations have been very good. Generally it has been a very fine example of the way an industry should be run. Yet you might argue that if there were only one oil company in the United States today, perhaps the cost could be lowered because of the lack of duplication.

Mr. DADDARIO. Isn't it a fallacy in your theory, and that is what I am aiming at in this analogy you draw, the fact that in the oil industry there have been millions of dollars spent by oil companies which went broke as a result of not being able to keep pace with this competitive demand, while in this particular case, nobody goes broke because the Government keeps feeding money into the pipeline.

There is a fallacy to this analogy that you draw as a result. It seems to me that there is a little bit too much of this business of applying the same techniques of competition in private industry where you have the inefficient companies in competition with the efficient ones and there is a fallout and as a result there is development because you get rid of inefficiencies in a natural manner, which does not apply to this theory that you have brought up.

Therefore, I think competition is fine, but wouldn't you say that somebody has to watch over the experiments. Somebody has to be able to say in an objective manner "this will do the job, let's now cut out the experiments and let's get into some other field." Let's use all these people. We hear time and time again you don't have enough scientists, you don't have enough people with technical knowledge. If they are working in the same direction it would seem to me that one way to eliminate waste is to eliminate waste in manpower and to divert them into other fields as quickly as possible—as soon as we have been able to complete an experiment.

Wouldn't you say this is true?

Dr. RITCHEY. Don't misunderstand me. I am making a case for competition which I think is extremely important. But I am not making a case for competition without any control whatsoever—competition let's say, that is not controlled by the customer himself, who is capable of deciding what is best for him. As long as the customer is capable of deciding what is best and controls the competition on this basis, there will not be any trouble with competition.

The evils that we have suffered in the past have been suffered solely because a whole host of extraneous factors have been used to judge what is best for the customer. If our customer, which is the Government, will set up a complete set of realistic values upon which he wants his product built, I don't think there will be any question but what competition can be controlled in the proper way.

The CHAIRMAN. Any further questions?

Mr. DADDARIO. Then you say this has got to be, that we do have to have more exacting specifications to get this job done and we should eliminate some of these wasteful and duplicating features. Certainly they do exist even under this analogy you have brought up.

Dr. RITCHEY. There have been some of them; yes.

The CHAIRMAN. May I say this: Tomorrow we have as witnesses Dr. John P. Longwell of the special projects unit of Esso Research & Engineering. Mr. John M. Martin, general manager, explosives department of Hercules Powder. Mr. Richard D. Geckler, vice president, solid propellant plant, the Aerojet-General Corp., Sacramento, Calif. Dr. Harold W. Ritchey—we have him today, and we are going to have him tomorrow from Bristol, Pa., and Huntsville, Ala., and Dr. Edward H. Seymour, director of research, Reaction Motors Division, Thiokol Chemical Co.

We certainly thank you gentlemen very much for coming here and helping us. We think you have been of real help to the committee. If there is no further business, we will recess until tomorrow morning at 10 o'clock.

(Whereupon, at 4:10 p.m. the committee recessed, to reconvene at 10 a.m., Tuesday, March 17, 1959.)

SPACE PROPULSION

HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., Tuesday, March 17, 1959.

The committee met at 10:05 a.m., in room B–214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. The committee will please come to order.

I was waiting just a moment for Mr. Ducander, but he will be in in a moment.

This morning we have before us, gentlemen of the committee, four witnesses. We have Dr. John P. Longwell, who is the head of the special projects unit of the Esso Research & Engineering Co. of Linden, N.J. We have Mr. John M. Martin, general manager of the explosives department of the Hercules Powder Co., Wilmington, Del., and Richard D. Geckler, vice president of the solid rocket plant of the Aerojet-General Corp., Sacramento, Calif., and then we have again, this morning, Dr. Harold W. Ritchey, vice president and technical director of the Rocket Division of Thiokol Chemical Co. of Bristol, Pa., and Huntsville, Ala.

We are not going to be able to meet this afternoon. My thought is, if it is all right with the committee, that we will hear these witnesses in their main presentation and then we can question them in all the time that we have left. I state to you gentlemen who are witnesses, this committee is eager to get all of the available information regarding this matter. We appreciate your cooperation in coming here and testifying this morning.

So at the outset I will call on Dr. Longwell of the Esso Research & Engineering Co. of Linden, N.J.

Dr. Longwell, you have a prepared statement, I believe, haven't you?

STATEMENT OF DR. JOHN P. LONGWELL, HEAD, SPECIAL PROJECTS UNIT, ESSO RESEARCH & ENGINEERING CO., LINDEN, N.J.

Dr. LONGWELL. Yes, I have.

Mr. FULTON. Will he identify his company and his connection?

The CHAIRMAN. Esso Research & Engineering Co. Is that a part of the Standard of New Jersey?

Dr. LONGWELL. Yes; it is the main technical research part of Standard of New Jersey.

The CHAIRMAN. That is the portion of it devoted to technical research?

Dr. LONGWELL. That is right.

Mr. FULTON. It is a wholly owned subsidiary, is it, or is it a non-profit corporation?

Dr. LONGWELL. It is a wholly owned affiliate. Although organized as a corporation, it is nonprofit.

The CHAIRMAN. Do you in the course of your statement give us the size of the research and development program that you carry on? If you don't, we would appreciate some information for the benefit of the committee, showing the size of your research program.

Dr. LONGWELL. The total size of the Standard of New Jersey research is around $65 million a year. Esso Research itself is roughly half that. There are other research organizations in the New Jersey company.

Mr. FULTON. That is the point of the question—if you would set up for us what the corporate structure is on research and development of Standard Oil of New Jersey and some other places in the record—not now.

The CHAIRMAN. I think that would be excellent information for us to get from all of the companies. What we are trying to do ultimately is to have a census made of the amount of research and development throughout the United States, both public and private. We are working on it in the United States Government, but you can help, and other witnesses can too, in private research.

If you will, sir, proceed with your prepared statement; we will appreciate it.

Dr. LONGWELL. These organizational matters were not included in the prepared statement.

The CHAIRMAN. You can go as far as you wish in that respect.

Dr. LONGWELL. I might just expand a little bit on the organization. There are a little over 200 affiliated companies that make up the Standard Oil of New Jersey. The Esso Research & Engineering Co. is one of these that handles a very large fraction of the engineering and the research.

There are other parts of the company that do this. Some of the operating affiliates have their own smaller research organizations, and there is also a company called Jersey Production Research that does research on the problem of finding oil and getting oil out of the ground, which is really quite separate from the chemical, the petrochemical work, and the manufacturing research that Esso Research & Engineering handles.

The CHAIRMAN. Your research covers explosives and propellants?

Dr. LONGWELL. It does at the present time. We have recently undertaken some work on advanced solid propellants under contract with the Army for the Advanced Research Projects Agency. In general we are interested in the energy business and look on rocket fuels as a branch of that.

The CHAIRMAN. Just proceed then with your statement.

Dr. LONGWELL. I will skip the first couple of lines since I have already gone over that. My interests in the field of propulsion have been concentrated on research on high performance engines as contrasted to development of engines from existing knowledge. My remarks today are therefore concentrated on the effect of research on the performance and the applications of solid propellant rockets.

A statement on the place of the various propulsion systems in space and missile technology when made today is based on judgment regard-

ing both the actual and potential performance of these choices. One can look at this problem from the viewpoint of development of a particular vehicle using known techniques and materials or one can attempt to foresee the improvements that may take place in order to guide the choices now being made and to justify research leading to improved propulsion.

Ultimately the choice of propulsion systems for space flight and for military missiles will be determined, not by the comparisons and opinions that we have today, but on the performance of these devices when full advantage is taken of the materials and techniques that the laws of nature make available to us.

It is, of course, not possible to accurately predict the results of research; however, one can obtain useful guidance from the limitations that seem to be imposed by known chemical elements and the laws of nature as we now understand them. Knowledge of the known chemical elements and their known combinations indicates that the most efficient chemical propellants are liquefied gases, such as liquid hydrogen, liquid fluorine, and liquid ozone.

These materials, as you know, require storage at very low temperatures and the time-consuming difficulties in handling them seems to rule them out for military applications where a state of instant readiness is necessary.

A practical solution to the problem is to chemically combine these elements with others so that the resulting material is either a solid or a liquid storable under normal atmospheric conditions. The forces that hold these elements together reduce the available energy and it is necessary to introduce less desirable elements such as nitrogen as used in nitric acid, or carbon as used in gasoline, and in conventional jet fuels to bind the more desirable elements of oxygen and hydrogen by chemical combination.

Generally speaking, more binding energy and a larger proportion of the less desirable elements are required to form a solid than a liquid propellant, so we can expect the storable liquid propellant to inherently deliver somewhat more impulse for a given weight of propellant. Since the small molecules used in liquid propellants are simpler and better known, it was possible early in the history of rockets to choose quite good liquid propellants, while available materials gave solid propellants of relatively low performance.

Research on solid propellants has, however, resulted in spectacular gains in performance due to two things: Development of higher energy propellants, and improved control of their burning rate so that the weight of the rocket case could be greatly reduced. Further gains are foreseeable and I expect that the gap will be further reduced, but not completely eliminated. What the final gap will be is hard to guess, but it will probably be under 10 percent in specific impulse—which is a measure of the amount of thrust for a given amount of propellant.

The weight of metal parts is also of great importance since they reduce the payload and limit the velocity that can be obtained. Here again, the liquid propellants started out with a considerable advantage, but this margin of advantage has narrowed rapidly with time.

For both solid and liquid propellant engines, it appears that the weight of metal parts will be less than 10 percent of the total engine plus propellant weight. When one carries a payload of appreciable size, the importance of differences in the weight of engine parts becomes less important as they become a smaller part of the total engine weight.

While the liquid propellant engine will probably retain some advantage in having less weight of engine parts, the magnitude of this advantage is expected to diminish with time, since payloads will become a larger fraction of the weight that is left after the propellants are consumed.

We are therefore left with the conclusion that we can expect storable liquid propellant engines to retain some advantage in weight required to do the same job, as compared with solid propellants, and that this advantage must be balanced against the advantage that solid propellant engines have in compactness and reliability.

Again looking into the future, it is expected that liquid propellant engines will improve in this regard, but solid propellant engines will retain an advantage. The importance of this advantage in reliability is not expected to diminish with time.

The premium for instant readiness and absolute reliability of military weapons becomes higher with each year and when the time comes to send men into space, an increase in total weight would certainly be acceptable if it increases the chances of a safe trip. These considerations apply particularly to the second and subsequent stages of the rocket, since the first stage for space flight is less critical, from a safety viewpoint since techniques for escaping following malfunction of the first stage can probably be worked out in view of the relatively low velocities involved. Also, the very large size and cost of the first stage seems to favor the use of liquid propellants because development of very large liquid propellant units now appears easier, as do the problems of recovering and reusing the first stage engine.

I would also like to say a few words about a specific area of research on rocket engines. Up until the last year relatively little research was done on synthesizing new compounds which would give propellants of greatly improved performance. A considerable amount of work was done on application of known types of materials and considerable progress was made by doing this.

It has now become apparent that important further gains in propellant performance can be expected to arise from synthesis of new compounds, and that a sizable effort in chemical research on radically new propellants is justified. Such a program has recently been started by the Defense Department.

It is expected that a successful program in propellant chemistry will result in at least 10 percent gain in specific impulse over the best of present solid propellants and that with a gain of this magnitude, the payload in a multistage rocket can be increased by approximately 50 per cent by substitution of such a propellant in the final stage rocket for those now available.

It is my opinion that, in view of the large gains in performance that new materials might provide, research in chemistry leading to improved propellants and materials of construction has been underfunded, relative to our capabilities of doing research in this field.

While there appears to be a general industry shortage of Ph. D. chemists, a smaller proportion of them are engaged in defense work than in the electrical and mechanical research fields.

Thus, it is easier to enlist highly trained chemical research personnel. These resources are quite large and we are therefore in a position to make more rapid advances in the field of materials resulting from research in chemistry, and by doing so would relieve many of the problems that now call for mechanical and electrical research for their solution.

In summary, it is believed that performance of storable liquid propellant rockets, and solid propellant rockets will be close enough that reliability will be a deciding factor in favor of solid propellants for most military applications, and possibly for use in second and subsequent stages of space vehicles. It is also believed that emphasis should be given to exploratory research on chemistry and metallurgy since further improvements depend on new materials and since as a Nation we are fortunate in having a large number of scientists with advanced training in chemistry.

The CHAIRMAN. Thank you very much, Dr. Longwell. We appreciate that statement. It is concise, and it is certainly to the point. In accordance with our program, we will call on Mr. John M. Martin, general manager, Explosives Division of the Hercules Powder Co., Wilmington, Del.

Mr. Martin?

STATEMENT OF JOHN M. MARTIN, MEMBER OF THE BOARD OF DIRECTORS, AND GENERAL MANAGER, EXPLOSIVES DEPARTMENT, HERCULES POWDER CO.

Mr. MARTIN. Mr. Chairman and members of the Committee on Science and Astronautics, I would like to read my statement, if I may.

The Hercules Powder Co. has been producing solid propellants for nearly half a century. For much of that period, their primary application has been for cannons, rifles, and other types of guns. Early in World War II, in cooperation with the Army, we developed a solid propellant charge for the first American rocket—the Bazooka—and since that time we have been called upon to develop and modify propellants to meet the requirements of a large variety of propulsion units.

The thousands of barrage rockets used against the enemy defenses in the Pacific campaign, and the airborne rockets that added to our offensive strength in the Pacific and over Korea, were powered by solid propellant charges, essentially all of which were produced by Hercules at one of several Government-owned plants. At the close of hostilities in World War II, attention was directed towards missiles of longer range and heavier payloads.

Propellant charges were designed and developed by Hercules, in cooperation with all three services, for such well-known units as the Nike, Terrier, Talos, Snark, Honest John, and other newer units.

It is significant that the short development lead time required for solid propellant charges made it possible to have such units ready for operational use under the pressure of accelerated wartime demands,

which in some respects are similar to those that concern us at the moment.

For 45 years Hercules has been concerned with the application and use of double-base propellants. These are made from raw materials which are available in more than adequate quantities, as demonstrated by the enormous production of World War II.

Cellulose, either from cotton or from wood pulp, is treated with nitric acid to form nitrocellulose; and glycerin, either the natural or synthetic variety, is similarly treated to form nitroglycerin. These ingredients are combined to form a solid plastic mass known as double-base propellant. The performance of the material can be modified and controlled by (a) altering the proportion of the two ingredients; (b) adding other chemicals to the basic mixture; and (c) changing the geometrical form.

Geometry is important since all solid propellants have one fundamental property; burning begins on all exposed surfaces and continues inwardly at a uniform rate, very much as the burning surface moves down the length of a cigarette as it is consumed. In the case of double-base, as with other solid propellants, all the oxygen required for combustion is incorporated in the material, and no outside source is needed.

While the combination of nitrocellulose and nitroglycerin is an excellent propellant in its own right, it is also an outstanding high-energy binder for other materials that may add to the overall performance of a rocket engine. Powdered metals, such as aluminum and boron, together with their derivatives or other high-energy materials, may be added to the double-base matrix to further increase the impulse level.

Through the popular magazines we have all become familiar with the term "specific impulse" as a gage for comparing the performance capabilities of available propellants. Specific impulse is probably the best yardstick available for comparing the possible performance levels of different propellant systems.

However, the ability to utilize available impulse under actual burning conditions makes it necessary to consider other significant factors. For example, the propellant made by Hercules for barrage rockets of World War II had a specific impulse as high or higher than that of many solid propellants that are finding useful application in the space efforts of 1959.

I think it might be interesting to the committee if I could stage just a minor illustration here of what we are talking about on these various propellants, the old type versus the new. This is sort of a crude demonstration but I think it will illustrate somewhat the difference in potential. This is the old type propellant [illustrating]. You will notice a small strand of it burns very slowly, and in an orderly manner, and this is an example of what might be called a low impulse propellant. You can extinguish it by blowing it out.

This is one of the higher impulse types [again illustrating] and I think you will notice a marked difference in just the visible effects of burning a very small strand. It will give some indication of the difference in intensity of burning.

It has other additives in with the binder and the fuel to give it quite an improvement in impulse. It is very difficult to blow out, and sustains burning very readily.

There are other properties, such as temperature and pressure sensitivity, that make our newer propellants more attractive, and there have been improvements in other parts of the rocket engine that have made it possible to use the potential of the fuel to greater advantage.

Perhaps the most obvious area of improvement has been in the case itself. We have made considerable progress in reducing the weight of the vessel needed to hold the pressures which are developed as the charge burns. Most rocket cases have been made of steel or other metals.

In the course of Hercules research, aimed at weight reduction of inert parts, we have developed a glass reinforced plastic case that has demonstrated exceptional advantages, especially for later stages. This material is equivalent in weight to magnesium, and its strength is comparable with that of many heat-treated steels.

Its strength-to-weight ratio far exceeds that of any known steel. A rocket engine case of this material requires less energy to push into the stratosphere than the heavy units that were available a short time ago. The metal parts that were required to contain the propellant charge of early rockets weighed as much as the propellant charge itself. Development effort in this area has greatly improved the mass ratio, so that today more than 92 percent of the total weight can be useful energy.

This is an example of this material which will easily support the weight of a man standing on it unsupported. It is a mixture of fiberglass fibers reinforced with a resin.

Until recently the role of solid fuel systems in the space program has been limited to relatively small but high-performance engines required for final stages to carry instrumentation to the desired velocities. For example, it has been announced by the National Aeronautics and Space Administration that a solid propellant engine of a type originally developed by Hercules for Vanguard is scheduled for use in four planned space probes this year. NASA also plans to use this unit and another made by Hercules of higher energy for the third and fourth stages of their Scout rocket.

In recognition of accomplishments of such units, the Navy adopted solid systems for both stages of Polaris missile, and with very obvious advantages which have been well publicized. As a result, Hercules and other major solid propellant producers are now developing units of greater capabilities for the Air Force Minuteman program, as well as the Navy Polaris, and other applications.

There are many advantages to using solid propellants for such large applications. Chief among these advantages are reliability, simplicity, elimination of lengthy countdowns. Also, we can't ignore the fact that transportation of large engines can be a major problem. Production techniques for double-base charges make it feasible to produce and assemble the complete unit, including the plastic chamber, at the point of intended launch.

As we expand the objectives of a space-exploration program, we find a need for even larger rocket engines that any that are now under development. The scaling up of present designs for solid fuel charges does not appear to present any unsurmountable problems.

We have come a long way since those first Bazooka charges were produced, and the increase to charges of sufficient size for use as a first-

stage space vehicle will present interesting new technical problems that our scientists would appreciate an opportunity to solve. We recognize that such a program will be difficult and expensive, but with the proper backing, it can be done.

Solid propellant research, development, and production are carried out by Hercules at the following locations:

Bacchus, Utah: Hercules plant, capable of developing and producing large solid propellant grains for both missiles and space vehicles.

Kenvil, N.J.: Development and production facility for solid propellent grains and propulsion units of small or medium size.

Allegany Ballistics Laboratory, Cumberland, Md.: A research and development facility operated by Hercules for the Navy Bureau of Ordnance. Has originated and passed on for production many of the solid propellant rockets in use today.

Radford Arsenal, Radford, Va.: An Army Ordnance facility built by Hercules and operated for the production of such field-use rockets as Nike, Honest John, Little John, as well as other propellants.

Sunflower Ordnance Works, Lawrence, Kans.: Schedules to be on standby. Built and operated by Hercules to produce rocket propellants.

The CHAIRMAN. Now, sir, would you care to place in the record something about the size or the scope or character or money value of your R. and D. program, research and development.

Mr. MARTIN. Yes, sir. Our program is centered at our research center in Wilmington, Del. We have some outlying facilities, but that is where our main effort is located. It amounts to, in dollar value, about $10 million a year, about 5 percent of our sales, our annual sales.

The CHAIRMAN. We thank you very much, sir. Let's push on to the statement of Mr. Richard Geckler.

Mr. Geckler is vice president of the solid rocket plant of Aerojet-General Corp. of Sacramento, Calif. Mr. Geckler, you have a prepared statement, sir. We would appreciate your proceeding with it.

STATEMENT OF RICHARD D. GECKLER, VICE PRESIDENT, SOLID ROCKET PLANT, AEROJET-GENERAL CORP., SACRAMENTO, CALIF.

Mr. GECKLER. All right, I have one and I will read it now.

In the literature of rocket development it is recorded that after many disappointing trials with solid-propellant rockets, the early amateur rocket enthusiasts unanimously concluded that progress toward their goal of space flight would come about only if they switched to liquid propellants. One of the best books on the history of rocketry comments, for example, that—

> even the most ordinary of liquid fuels, ordinary automotive gasoline, will produce an exhaust velocity about twice that of a black powder rocket.

In the light of such comments it is pertinent to ask why solid-propellant rockets should be seriously considered for any applications when there are many combinations of liquid propellants available for use in rocket powerplants.

The answer lies in the fact that new solid propellants far superior to black powder were invented and tailored specifically to meet rocket

requirements while at the same time the scientific and engineering principles of rocket design were greatly refined.

As a consequence we have today solid propellants of nearly equal performance to that of the commonly used liquid propellants such as oxygen-kerosene while the simplicity of design has led to extremely high reliability of operation. For example, the 15-second duration, 1,000-pound thrust JATO rocket manufactured by my company has an observed reliability of 99.998 percent in about 85,000 firings.

This high reliability of solid-propellant rockets, coupled with their other outstanding characteristic, namely much simpler field servicing procedures, has led to their ever greater acceptance by the Armed Forces in weapon system applications. The Polaris and Minuteman weapon systems are outstanding examples of this type of use of solid-propellant rockets.

For the propulsion systems needed in the exploration of space it is by no means clear what role will be played eventually by solid-propellant rockets. At the present time we see no way of achieving with solid propellants an exhaust velocity as great as can be obtained by liquid hydrogen burned with either liquid oxygen or liquid fluorine.

On the other hand, propellant performance is not necessarily the determining factor in selecting the type of powerplant for any space mission. I personally believe that chemical rockets will not be supplanted in space exploration for many years to come, and that the special characteristics of solid propellants will enable them to compete effectively with liquid propellants.

The storability, reliability, and simplicity in operational use of solid-propellant rockets are all characteristics vital to successful space exploration that are sufficient to justify continued aggressive development of solid rockets.

Although great improvements in performance of solid propellants have been made in the last few years, there is still room for additional advances. These will require the construction of new facilities for the manufacture of presently unavailable raw materials with which to produce better propellants as well as expanded research and development to obtain new propellant formulations.

By far the most important requirement in rocket propulsion for the space age is the construction of larger rockets. In order to put larger payloads into space, we must have larger propulsion systems. For liquid-propellant rockets this requirement is commonly expressed in terms of the need for higher levels of thrust.

For solid-propellant rockets, on the contrary, it is comparatively easy to achieve as high a thrust as desired. What is more significant is the total weight of the rocket. An immediate step to extend our technology would be the development of solid-propellant rockets weighing on the order of 100,000 pounds. However, there is every reason to commence the development of much larger sizes as well.

The ultimate factor governing the selection of propulsion systems for space exploration will probably be cost. This is a complex question for which definitive answers apparently do not exist at the present time. Under normal conditions a solid-propellant rocket will cost somewhere between $2 and $10 per pound of total loaded weight.

The smaller figure is applicable to simpler designs at a relatively high production level; the larger figure is applicable to more compli-

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cated designs at relatively low levels of production. Even lower and higher figures are possible under exceptional circumstances.

Because large production levels are not likely to be achieved with propulsion systems for space exploration, the development cost can be an appreciable factor requiring consideration. Moreover, the costs associated with field operations are influenced by the type of propulsion system being used.

In view of these complicating factors I believe it would be misleading to make any final assertions regarding the comparative costs of liquid and solid-propellant rockets. However, there is no indication that solid rockets could not compete favorably under most circumstances.

In conclusion I should like to state that in view of the rapidly changing technology and the variety of circumstances governing the use of rocket powerplants it is virtually impossible to give a clear-cut answer to the often-asked question, "Which is better, liquids or solids?"

Our position today in rocket development may be similar to the early days of automobile development when the comparative merits of the internal combustion engine and the steam engine required many years to finally assess. With the accumulation of additional experience we may eventually establish that solid- and liquid-propellant rockets are substantially equivalent as is the case with matches and cigarette lighters. To ask which is the better, is almost a meaningless question.

In the meantime continued development of both solids and liquids with adequate attention to areas requiring basic research appears necessary for accomplishing the next steps in our conquest of space.

The CHAIRMAN. Thank you very much, Mr. Geckler. Those are three excellent statements, every one of them, very fine.

Now we have Dr. Harold W. Ritchey, vice president and technical director of Thiokol Chemical Corp.

Doctor, you have a statement here, a rather lengthy statement, for our committee. But a part of it is made up with diagrams. Do you want to follow the statement?

Dr. RITCHEY. I would prefer not to, Mr. Chairman. I am going to follow the thoughts in the statement but not the direct wording because it is too long. Because of this I have passed out the diagrams in a separate form and from time to time I will refer to these as I am talking.

The CHAIRMAN. Excuse me just a moment. If I could ask Mr. Geckler, could you on behalf of the Aerojet-General Corp. give us some idea—you could put it in the record if you wish to—of the size and the scope of your R. & D. program there, in dollars and cents, and the characteristics of it if you wish?

Mr. GECKLER. Yes, sir. The solid rocket plant employs about 5,000 people. It conducts almost all of the research, development and production of solid rockets for the Aerojet-General Corp. The total corporation has about 17,000 people.

The CHAIRMAN. Would you say 5,000 people are the extent of the R. & D. program?

Mr. GECKLER. No, sir. Approximately 80 percent of that would be research and development. The other 20 percent would be routine production.

The CHAIRMAN. What would you estimate your cost at?

Mr. GECKLER. This year it would be something in excess of $150 million.

The CHAIRMAN. We certainly thank you.

Dr. RITCHEY. As I said, gentlemen, I will follow the thoughts in the prepared statement but not the exact wording so we can get through in a little less time than it would take to read it.

STATEMENT OF DR. HAROLD W. RITCHEY, VICE PRESIDENT AND TECHNICAL DIRECTOR, ROCKET DIVISIONS, THIOKOL CHEMICAL CORP.

(The following prepared statement was filed for the record:)

The area in which Thiokol solid propellant motors are applicable to space can be divided into two general classes. One is the method for propelling the desired vehicle into space, and the second is the method for operating and maneuvering the vehicle after it is in space.

Since current problems are primarily associated with getting into space, we shall limit this discussion to the first area. It appears that the immediate future is divided also into two requirement areas. The first is the propulsion of experimental, test type vehicles for space research exploration to obtain scientific data. Such investigations will require large numbers of vehicles and, therefore, the economy and reliability as currently demonstrated by solid propellant rocket motors is a paramount feature of this first area.

The second area is the propulsion of vehicles to reach the objective of operating in space, which means that we must accelerate larger payloads to satellite and escape velocities. There appears to be a common misconception of the term "payload." It is defined here as that weight of instruments, nose cone, equipment, etc., that is placed in orbit or pushed to escape velocity. That portion of the propulsion system which is also accelerated to final velocity is not included in the payload weights.

The acceleration of an object in space is a rather involved technical subject. In general, the smaller the payload with respect to the size of the powerplant, the higher the velocity that will be achieved. If the payload rate is reduced to zero, however, there is no useful payload weight, but acceleration must be applied to those portions of the propulsion system that remain after the fuel has been completely expended. In general, this remaining portion includes the case, nozzle and any motor controls that may be required. Thiokol research and development is directed toward the reduction of the weight of these items in order to reduce the weight of inert components that must be accelerated to final velocity. This requires a concentrated research and development effort in many fields. These fields include propellant chemistry, chemical thermodynamics, high polymer research, propellant formulation, combustion kinetics, metallurgical improvements of inert components, plastic insulation and components, nozzle and case fabrication, and practically all fields of scientific endeavor. The object of this work is to increase the performance of solid propellant motors so that larger payloads can be placed into orbit or space.

In general, there are two primary features of a propulsion unit which must be considered in relation to performance. The first is commonly referred to as specific impulse, the energy of the propellant. The second is the propellant weight fraction, which is the ratio of propellant weight to the total weight of the powerplant. Current weight fractions are between 85 and 90 percent. The weight fractions of some items encountered in everyday life may be useful for comparison purposes.

A can of beer is 81.4 percent payload and the rest of it is inert components, the can itself. If rockets were made so poorly, little would be accomplished.

An egg is a little better, with 89.6 percent of useful content and the rest shell. This is within the range of solid rocket motors.

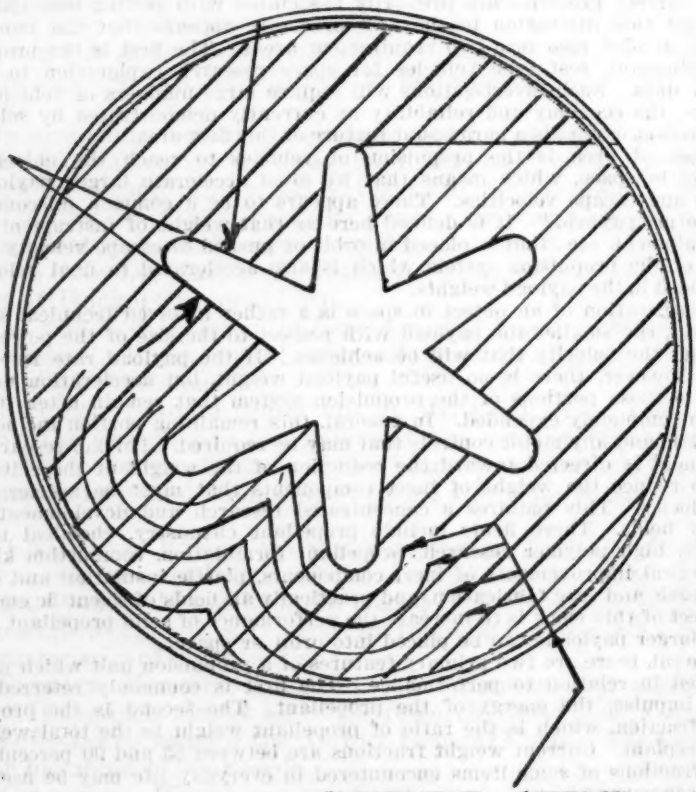
A candy bar's ratio of useful content to total weight is 95.6 percent, which is relatively good. Many rockets flying today are not nearly so good as the candy bar.

A packaged loaf of bread is even better with 97.7 percent of usable weight. This is a fine objective to set but there is a tremendous amount of work ahead before such weight fractions can be achieved for solid propellant rocket motors. A motor case and nozzle is not just a wrapper around the propellant. The case must sustain pressure and the nozzle must withstand heat above the melting point of steel or the rocket will not work, so achieving something close to the packaging efficiency of a loaf of bread looks like a most difficult proposition.

Weight fractions of 85 to 90 percent represent a significant improvement over World War II rockets. This major stride forward in performance has been primarily attributable to the case-bonded, internal burning solid propellant type motor. The case-bonded internal burning technique was invented at the end of World War II by the Jet Propulsion Laboratory under Army sponsorship. Thiokol was engaged by the Army to develop this technology and to apply it to complete rocket motors. During the entire period of activity in the solid propellant motor field, Thiokol has used this advanced technique in all of its many rocket motor development programs.

Figure 1 shows a cross-section of an internal burning, case-bonded solid propellant rocket motor.

FIGURE 1



Cross section of typical internal burning case-bonded configuration.

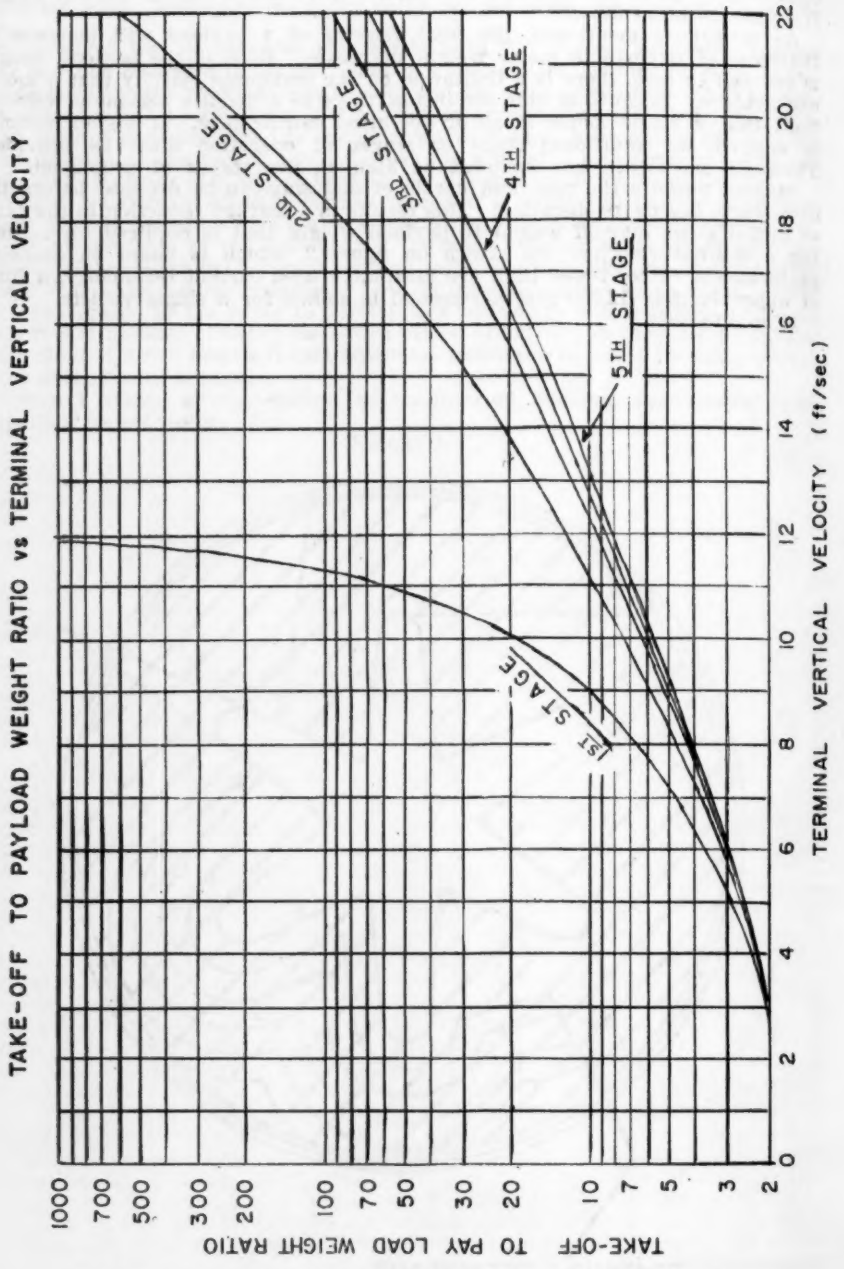
The propellant burns from the inside outward in a uniform fashion and at an even rate from all exposed burning surfaces. The case is protected by the propellant itself from the heat of the combustion gases. Because of this, the case weight can be reduced to a minimum which enables high propellant weight fractions to be achieved.

As previously mentioned, the final velocity of a payload will increase as the ratio of payload to motor weight decreases. Even if the payload weight is reduced to zero, there is a limitation on the maximum velocity that a motor can achieve. Because of this limitation, there is a definite maximum velocity limit that a single motor stage of operation can achieve. If higher velocity is desired, an additional stage or stages of operation must be provided. Thiokol's experience has included as high as five stages of propulsion.

Staging permits the case and nozzle of one stage to be dropped before the next stages begins its operation. This results in a marked reduction in the ratio of initial gross take-off weight to payload weight that is required for achieving a desired velocity. As shown on figure 2, which is based on assumed performance values lower than are attainable with current technology, a limit of approximately 12,000 feet per second is shown for a single vehicle.

(Fig. 2 follows.)

FIGURE 2

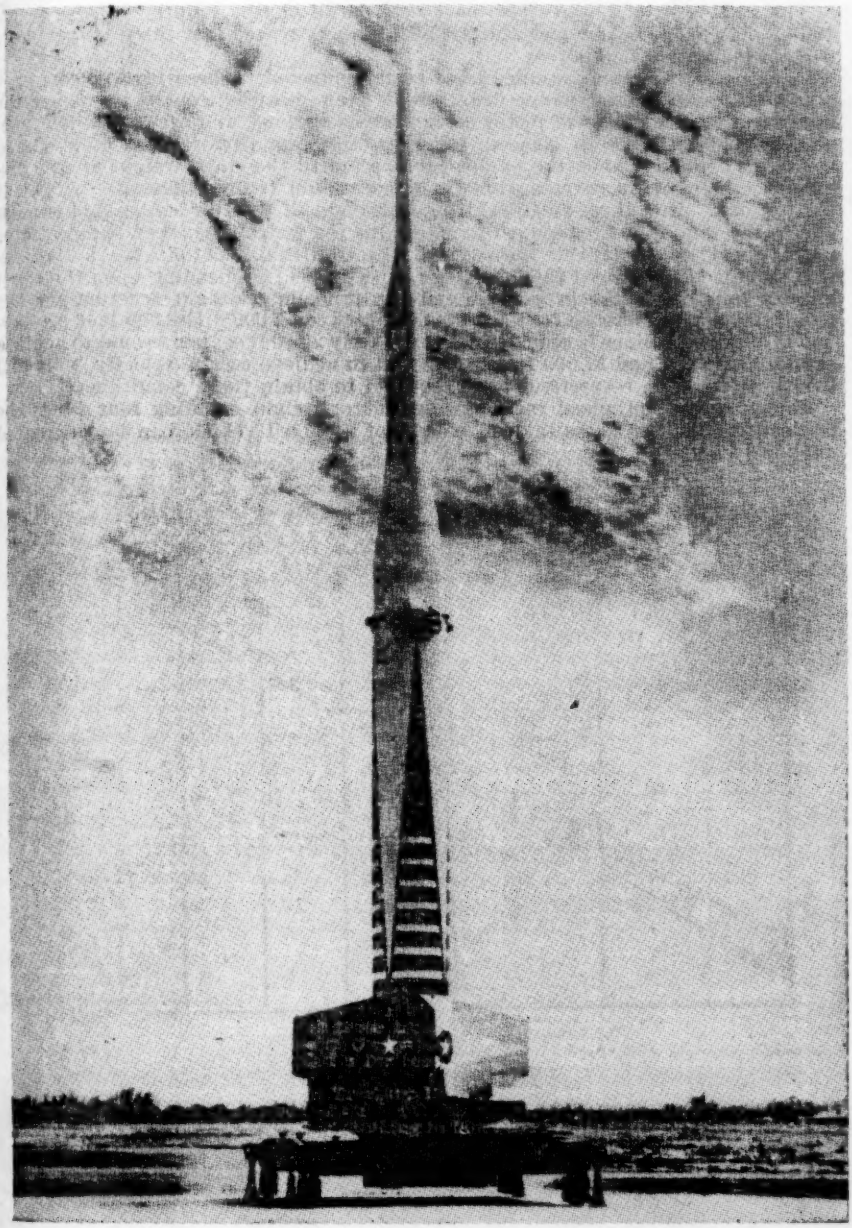


Takeoff to payload-weight ratio versus terminal vertical velocity.

By use of additional stages, higher velocities are attainable. For instance, a velocity of 20,000 feet per second can be obtained with two or more stages and the ratio of take-off weight to payload weight will decrease as more stages are used. For a two-stage vehicle, the gross take-off weight will be 200 times the payload weight, and for a three-stage vehicle, the gross take-off weight will be 50 times the payload weight.

One of the earliest well-known applications of a multiple stage vehicle was the Air Force-Lockheed re-entry test vehicle, designated as the X–17 and shown on figure 3.

FIGURE 3



Photograph of Lockheed-Air Force X–17 re-entry test vehicle.

The X–17 is a three-stage vehicle utilizing an XM20 as the first stage, three XM–19 motors bundled together to operate in unison as the second stage, and a single XM–19 as the third stage. Actually, this vehicle operated with the first stage accelerating the vehicle to altitude and the second and third stages accelerating the payload back to earth. In one case, however, a malfunction occurred in the firing circuitry and all three stages operated on the way up. This occurred in September of 1956, and although the final stage and payload were not recovered to our knowledge, calculations show that the range for this flight was approximately 860 nautical miles. This vehicle was used to determine reentry nose cone problems and tests were conducted from Patrick Air Force Base in 1956–58.

The staging principle has also been used in all of this country's space operations. The most recent was the Army's Juno II whose last three stages were solid propellant rocket motors.

Many detailed staging studies have been conducted. These involve considerations of gravity, aerodynamic drag, aerodynamic heating, control problems, the number of stages, effects of motor design considerations, and other detailed technical considerations. In general, however, optimum performance of a staged vehicle is achieved when the payload is one-fourth the stage weight of the propulsion system or, in reverse, that the stage weight is four times the weight of the payload. In a three-stage vehicle, the weight of the third-stage motor must add to the weight of the payload to determine the weight the second-stage motor must propel; the weight of the payload, the third-stage motor, and the second-stage motor is the weight the first stage must propel. Depending upon the exact specific impulse of the propellant and the propellant weight fraction for the motor, a velocity increase for each stage of between 7,000 and 8,000 feet per second is obtained. Since it requires approximately 25,000 feet per second to achieve satellite velocity and 37,000 feet per second to achieve escape velocity, four and five-stage vehicles, respectively, are required to obtain these conditions.

Following the optimized ratio of stage motor weight equaling four times the payload weight, the gross take-off weight of a staged vehicle can be calculated as shown in figure 4.

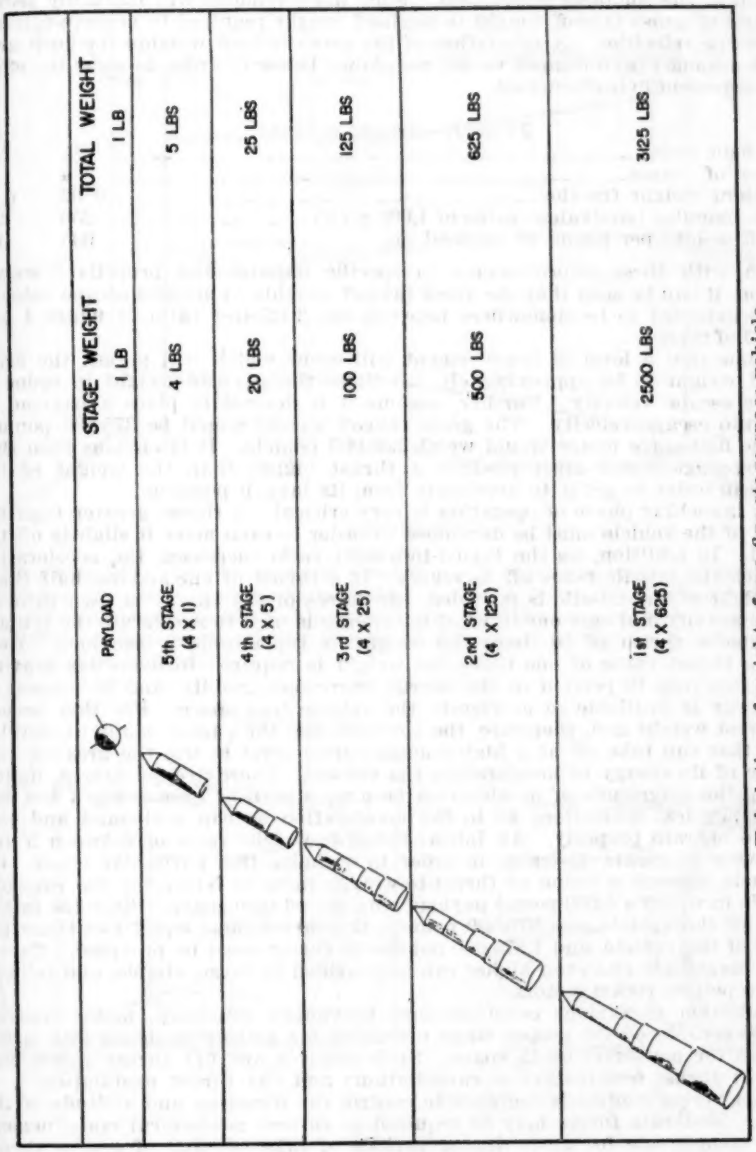


FIGURE 4

Tabulation of weights for a five-stage space vehicle.

As shown, a ratio of approximately 625 pounds per pound of payload is required for orbital velocity, and for escape velocity, a ratio of 3,125 pounds per pound of payload is required. Performance improvements which might be represented by the current state of the art or current development will, of course, improve both the specific impulse of the propellant and the propellant weight fraction of the complete powerplant. Such improvements will markedly reduce the ratio of gross takeoff weight to payload weight required to achieve satellite and escape velocities. A tabulation of the gross takeoff weights for such arbitrarily assumed performance values are shown below in order to show the effect of improvement in performance.

Table I.—Escape velocity

Stage load ratio	¼	¼
Number of stages	4	3
Propellant weight fraction	0.92	0.92
Specific impulse (equivalent value of 1,000 p.s.i.)	250	290
Takeoff weight per pound of payload	625	125

Even with these improvements in specific impulse and propellant weight fraction, it can be seen that the gross takeoff weights to achieve escape velocity can be expected to be somewhere between the 3,125-to-1 ratio of figure 4 and 125-to-1 of table 1.

Assume that a level of improvement will occur which will permit the gross takeoff weight to be approximately 125 times the payload weight in order to achieve escape velocity. Further, assume it is desired to place a payload of 3,000 into escape velocity. The gross takeoff weight would be 375,000 pounds, and the first-stage motor would weigh 300,000 pounds. It is obvious then that the first-stage motor must produce a thrust higher than the weight of the missile in order to get it to accelerate from its launch position.

This launching phase of operation is very critical. A thrust greater than the weight of the vehicle must be developed in order to even move it slightly off the ground. In addition, as the thrust-to-weight ratio increases, the acceleration at which the missile takes off increases. If a thrust of one-and-one-half times the weight of the missile is provided, two-thirds of the energy is used in overcoming gravity and only one-third of the energy is used to accelerate the vehicle.

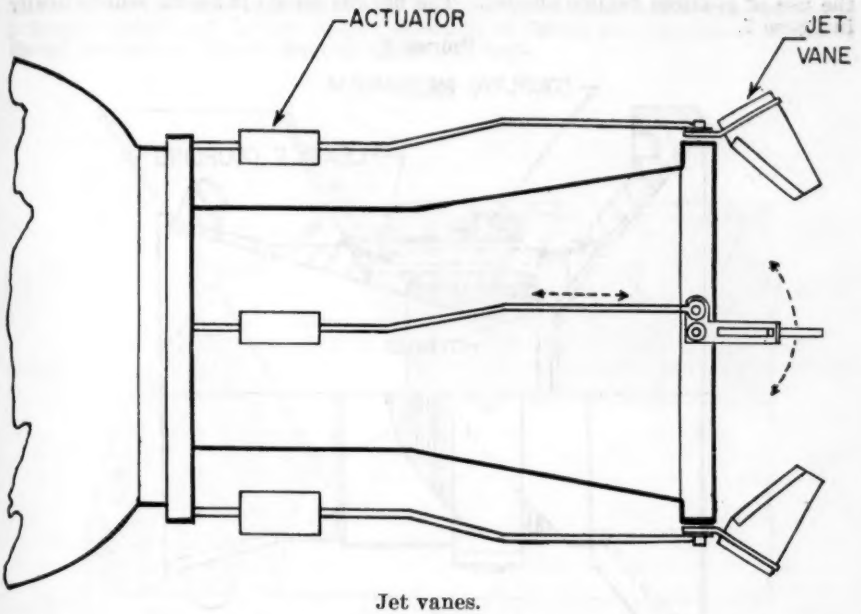
Assume a thrust of 10 times the weight of the missile is provided. Here again a thrust value of one times the weight is required to overcome gravity, but in this case 10 percent of the energy overcomes gravity, and 90 percent of the energy is available to accelerate the vehicle into space. For this reason, the lowest weight and, therefore, the cheapest and the easiest motor to develop is one that can take off at a high enough thrust level to use the greatest percentage of its energy in accelerating the vehicle. There are, of course, limitations to the magnitude of acceleration because a man or even a black box has certain physical limitations as to the acceleration he can withstand and continue to operate properly. An initial thrust-to-weight ratio of between 5 and 10, however, appears desirable in order to optimize this particular effect. On this basis, assume a value of thrust-to-weight ratio of 5-to-1 for the previous example in which a 3,000-pound payload was placed into space. Since the initial weight of the vehicle was 375,000 pounds, the thrust must equal five times the weight of the vehicle, and 1,875,000 pounds of thrust must be provided. Thrust of this magnitude and even higher can be provided by large, simple, and reliable solid propellant rocket motors.

In addition to various considerations previously discussed, motor controls must be considered for proper stage operation for getting payloads into space, and also for maneuvering in space. Such controls are (1) thrust vector control; (2) thrust termination or cancellation; and (3) thrust modulation.

Thrust vector control is required to control the direction and attitude of the vehicle. Moderate forces may be required to correct mechanical malalinement and to compensate for gusts during periods of take off, and of course thrust vector control is required at altitudes where the density of the atmosphere is not sufficient to permit aerodynamic control.

One of the old and classical methods for obtaining thrust vector control is by the use of jet vanes. Conventional applications usually require four jet vanes as shown in figure 5.

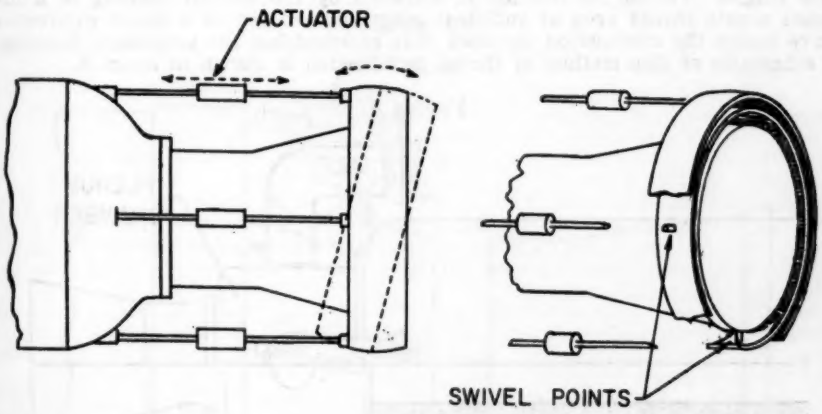
FIGURE 5



Jet vanes.

Jet vanes have the advantage of providing roll control as well as side vectors, but have the disadvantage of introducing thrust losses and present difficult material problems due to the high temperature of the exhaust gases. A second method of thrust vector control commonly referred to as the jetevator is shown schematically in figure 6.

FIGURE 6



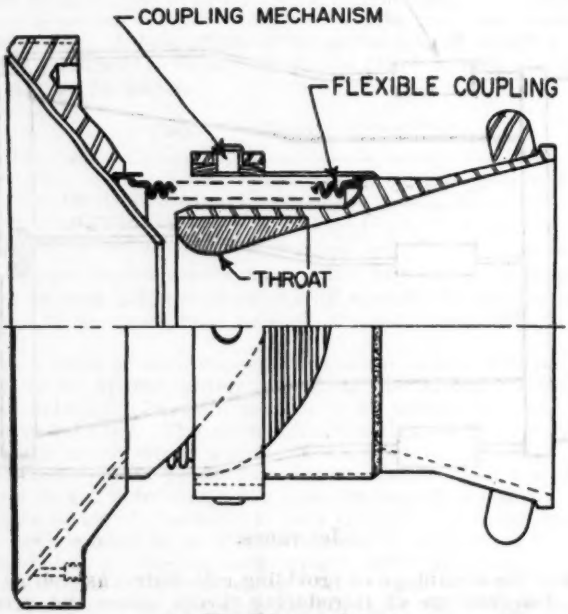
Jetevator.

In contrast to the jet vane, which is exposed to the high temperature gases during the entire operation of the motor, the jetevator is emerged in the jet stream only for the time the control forces are needed, thereby, overcoming some of the problems found in jet vanes.

The third device, flexible nozzles, is based upon the nozzle being connected to the motor by a flexible coupling. From the standpoint of drag loss, this

device is the most efficient of the three. Also, roll control can be obtained by the use of multiple flexible nozzles. The flexible nozzle is shown schematically in figure 7.

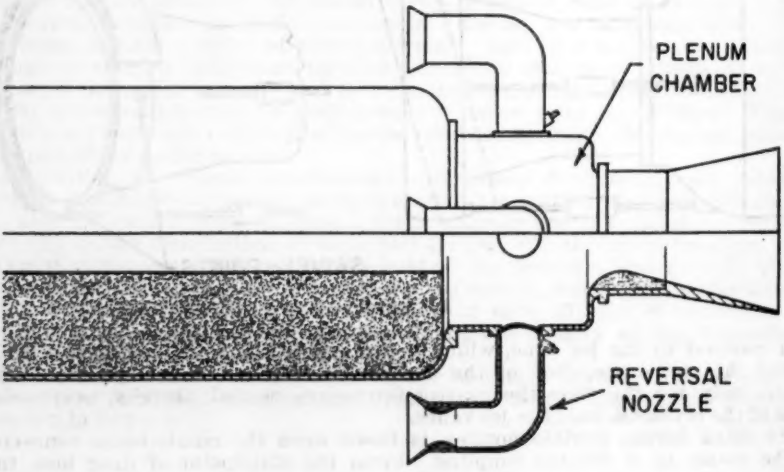
FIGURE 7



Flexible nozzle.

Thrust termination or cancellation is required for total impulse control in order to control precisely the final velocity and is sometimes necessary to separate stages. Thrust termination is achieved by the sudden opening of additional nozzle throat area of sufficient magnitude to set off a shock expansion wave inside the combustion chamber that extinguishes the propellant burning. A schematic of this method of thrust termination is shown in figure 8.

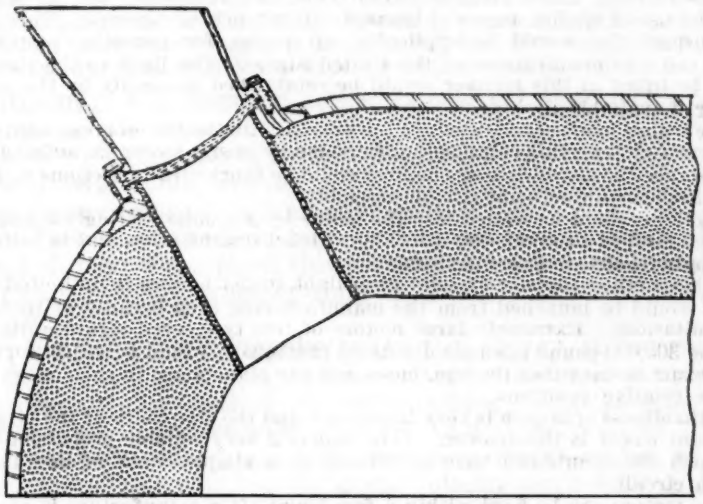
FIGURE 8



Aft-end thrust reversal system.

Thrust cancellation or thrust reversal is accomplished by opening additional nozzle throat area so that the thrust from the reversal nozzle is opposed to the primary nozzle and, by the proper selection of throat size, an actual negative thrust is obtained. This is demonstrated in figure 9.

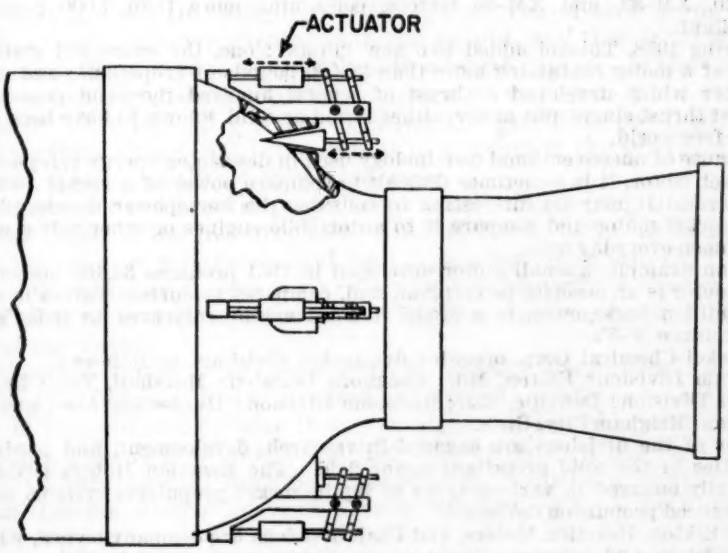
FIGURE 9



Head-end thrust reversal system.

Thrust modulation is desirable in order to vary the level of thrust during motor operation. Although a large amount of work yet remains to be done, it is believed to be entirely feasible to vary the throat size during motor operation, thereby varying the chamber pressure and resulting thrust level. Another possible method of accomplishing this is shown in figure 10.

FIGURE 10



Thrust level control.

Current physical size limitations of large solid propellant rocket motors are generally agreed to be approximately 80,000 pounds total weight and 12 feet in diameter. The 80,000 pound weight limitation is established by the load carrying capacities of highway and railway bridges.

The 12-foot-diameter limitation is established by the clearance of underpasses and obstructions along right-of-ways. This size limitation can be overcome easily by use of special means of transportation, such as airships. This method of transportation would be applicable, of course, for peacetime applications within the continental limits of the United States. The limit to the size which would be lifted in this manner would be established primarily by the size and number of available airships.

Since transportation facilities are the only size limitation on large solid propellant rocket motors, this can also be overcome by onsite motor manufacture. In this instance the motor case or chamber could be fabricated in sections and transported to the manufacturing site for assembly.

Propellant would be loaded into the motor by a mobile casting method which has been studied in great detail by the Thiokol organization and is believed to be not only feasible but very desirable.

By this method the size of solid propellant rocket motors is unlimited. Such motors would be launched from the manufacturing area because of transportation limitations. Extremely large motors of this type, even significantly larger than the 300,000-pound example discussed previously, would be ready for launch at the exact instant that the sun, moon and the planets are in their most advantageous relative positions.

The timeliness of launch is very important, and the simplicity of the large solid propellant motor is the answer. They supply a very reliable propulsion system for which the countdown time is reduced to a simple check of one electrical ignition circuit.

Large motors can be fired within a few hours after manufacture is completed or they can be stored indefinitely, ready for use within minutes after a decision is made to fire.

Thiokol's experience in the large solid propellant rocket motor field dates back to March 1953, with the manufacture of the first "large" motor, which was 50 times larger than any previously manufactured. This motor contained 5,000 pounds of propellant and was used to launch successfully the RV–A–10 Hermes test vehicle.

Further contributions to the large motor field followed with the XM–12 motor for the Sergeant missile, containing almost 6,000 pounds of propellant and the XM–20, XM–33, and XM–36 motors, containing more than 7,000 pounds of propellant.

During 1958, Thiokol added two new "firsts": one, the successful static test firing of a motor containing more than 20,000 pounds of propellant; and second, a motor which developed a thrust of several hundred thousand pounds—the highest thrust single unit motor, either liquid or solid, known to have been tested in the free world.

Because of unconventional terminology used in describing energy released from a rocket motor, it is sometimes difficult to compare power of a rocket to known standards. It may be interesting to consider the horsepower developed by a solid rocket motor and compare it to automobile engines or other prime movers in common everyday use.

As an example, a small motor developed in 1951 produces 33,400 horsepower. This motor is an obsolete powerplant, and, compared to current values in excess of 5 million horsepower, is a Model T Ford engine compared to today's high performance V–8's.

Thiokol Chemical Corp. operates five rocket divisions, as follows:

Elkton Division: Elkton, Md.; Longhorn Division: Marshall, Tex.; Reaction Motors Division: Denville, N.J.; Redstone Division: Huntsville, Ala.; and Utah Division: Brigham City, Utah.

Four of the divisions are engaged in research, development, and production activities in the solid propellant motor field. The Reaction Motors Division is primarily engaged in various types of liquid rocket propulsion systems as well as advanced propulsion devices.

The Elkton, Reaction Motors, and Utah divisions are company-owned, whereas the Redstone and Longhorn divisions are Government-owned facilities operated by Thiokol Chemical Corp. More than 21,000 acres are utilized by these divisions and there are more than 7,000 employees.

The contributions by Thiokol in the solid propellant motor field are well demonstrated by the development record and reliability of programs including Falcon, Lacrosse, Sergeant, Nike-Hercules, Matador, Polaris test vehicle, and the Lockheed X–17.

The reliance that is being placed on this organization is demonstrated by the importance of the programs in which it is currently engaged: production and improvement programs for the Falcon, Lacrosse, Sergeant, Nike-Hercules, and Matador; and development programs including Sub-Roc, Minuteman, Genii, Nike-Zeus, Bomarc, Pershing, and NASA space propulsion programs.

Dr. RITCHEY. We discussed rather extensively yesterday a lot of the things people expect of rockets. Some of these are low cost. Sometimes we expect them to operate over very wide temperature range or to be storable, let's say, under long-term conditions and in a very hostile environment such as outer space.

If you look at the technical requirements, however, you find two principal things, and a third thing, that are fundamental, applying to all rocket systems, whether solid or liquid. These three things are simply as follows:

First, the fuel specific impulse or the fuel energy, if you want to call it this. Second, the mass ratio of fuel to the inert components of the rocket engine—well, I am really talking about the mass ratio of fuel to the total rocket when it is loaded and ready to go. These two things are fundamental in the operation of any rocket, and the only two things that count so far as the velocity you can get by burning a rocket engine in outer space.

In the operation in a gravitational field there is a third thing that counts. This is the ratio of thrust to weight. The reason why this is important is simply this: When you burn a rocket you want the missile to move. If you tie a rocket down and burn it, all the energy in the fuel goes into the exhaust stream and no energy goes into the missile itself because the missile doesn't move.

The same thing is true if the missile is loose and free to go. If the thrust is less than the weight, it sits on the ground and burns fuel until the thrust becomes greater than the weight, and then it takes off.

The same thing is true when it flies, to a lesser degree. If the thrust is not appreciably greater than the weight, then we have a lot of energy wasted in what we call g losses, fighting the gravitational field. So there is a third thing that is important in a rocket in the gravitational field and this is the thrust-to-weight ratio.

Getting back to the solid propellant rockets: For a long time a controversy raged in the industry as to whether it was better to make the propellant charge separately and load it as a cartridge into the rocket engine, or whether it was better to mix the propellant charge as a liquid slurry, pour it into the rocket engine, and case-bond it to the shell of the vessel.

This latter concept was first started by the Jet Propulsion Laboratory in California. I was quizzed extensively yesterday about the price of Thiokol stock—why it was so high. If I could point to any one thing, I think it would be the fact that we hitched our fate to the future of the internal-burning, case-bonded propellant charge, and this has become almost universally accepted throughout the industry today.

In figure 1 (see p. 96) you have a cross section of the internal burning propellant charge, showing how the flame progresses from the inside perforation—which is a six-pointed star in this case—outward in

uniform layers. This can be designed so that the surface area stays constant, which means that you get a constant thrust with respect to time.

I have another configuration here which is an actual cross section cut from the Falcon engine. This is a dummy propellant. In this case we substituted ordinary table salt for the oxidizer so it will not burn. Incidentally, it also has staining characteristics, so be careful with it. That is the actual cross section from a Falcon engine except it is loaded with dummy propellant rather than live propellant. [Passes around the sample.]

The actual propellant has a characteristic of an old, beat-up pencil eraser. It is elastic, low modulus, very flexible. It has to be, in order to bond to the shell. It is quite safe. It does burn, however, when ignited, with a very intense flame as I will show you.

Here again I am going to pass these around. This is live propellant. When it is ignited, don't try to put it out, because you can't. [Passes around the sample.]

Mr. FULTON. Will you be able to put it out?

Dr. RITCHEY. You cannot. It will burn up. There is no way to put it out. I am going to burn a little bit of this for you. Here again I will probably start a fire or break the ashtray. [Demonstrates, producing a brilliant light and clouds of smoke.]

This material is made with an elastomeric binder that can be processed in a fluid form. I might say liquid, but it hardly describes it because it looks almost like toothpaste when mixed with ammonium perchlorate. Most of your propellants today, solid propellants, are based on ammonium perchlorate in one form or another, mixed with some kind of fuel binder.

Getting into some of the things that are important in the use of a solid propellant rocket engine, we have already mentioned fuel energy. I would like to mention briefly this question of mass ratio and staging. It is very important, as we have mentioned many times, to keep the inner components as light as possible, which means you must use as strong a structure to contain the propellant as possible, and also to try to shield it from the heat of the propellant flame during burning.

This is very important and is illustrated in figure 2 (see p. 98) to some extent, where you find that the maximum velocity you can get per stage—that is, the velocity you can get per stage does approach a maximum, depending upon its mass ratio.

Because of this, if you want to get high velocities as illustrated in figure 2, you must use multiple stages. In other words, as the rocket burns, you drop off the inert components when the first stage is burned out. If you have two stages or three stages, you keep dropping off the inert components as you go. Getting rid of these gives you effectively a higher mass ratio and a higher burn-out velocity.

Because of this, necessity for staging and the simplicity of solid rockets, they have been used on upper stages. Figure 3 (see p. 99) is an illustration here of the Lockheed Air Force X–17 reentry test vehicle. This weighed roughly five tons at take-off, and there have been several dozen of these fired in flight with practically no failures that could be attributed to the rocket engines.

This is a three-stage vehicle, and solid propellants, as I say, have been used extensively for upper stages because of their reliability and ease of ignition. This particular one was supposed to fire up into the air and then back down again in order to test the reentry conditions. The firing circuitry in one of them did go wrong and it went something over 800 miles as far as we can determine, even though it was not fired for maximum range.

The matter of staging, you understand, is much like asking yourself the question of how you would get up a very, very long hill, which of course, is the earth's gravitational hill, where there are no filling stations. If you wanted to go a long distance you might start out with a gasoline truck and alongside this you would tow a pickup truck with oil drums in it and finally after the gasoline is burned out of each successive vehicle you might get on a motorcycle and ride as far up the hill as you could. This is essentially the principle of the stage vehicle.

The more stages we put together, the farther up the hill we go, until finally we can climb the hill completely or achieve escape velocity.

In figure 4 (see p. 101) you will see some tabulations here using what you might call conventional existing solid propellant rockets as they might be put together today. These calculations are made approximately with the stage ratio of one to four. In other words, everything above the rocket engine that is burning weighs one-fourth of the rocket that is burning when the combustion actually started.

For mathematical reasons—I won't try to discuss this—this comes close to being the optimum staging ratio. In other words, a weight ratio of four to one is optimum for many purposes.

This (fig. 4) represents what might be done with existing solid rockets today for an escape velocity vehicle where, if we want to put one pound of payload to an escape velocity—let's say around the sun or past the moon—the takeoff weight of this vehicle at the time it was ignited on the ground would be about 3,125 pounds for each pound of payload.

With existing materials, this is approximately the problem we have facing us in the solid rocket fuels. With improvements, however, this ratio can be reduced. It is certainly very apparent it is important to reduce it, because if we want to put 1,000 pounds into escape velocity with this kind of a rocket, we would have over 3 million pounds of takeoff weight.

The effect of specific impulse in reducing this ratio is depicted in table No. 1. These calculations are made on exactly the same basis, except that the first column here has 250 specific impulse propellant at sea level conditions, and the second one has 290.

By increasing the specific impulse by this value we can reduce the takeoff weight from 625. By the way, the first calculation (fig. 4) was made with a different set of conditions; the ratio 3,125 involved a lower specific impulse and a lower mass ratio. With a specific impulse of 250 and a mass ratio of 92 percent—in other words, the rocket engine itself is 92 percent propellant—we have a ratio of 625 pounds of takeoff weight to one of payload to get escape velocity.

41260—59——8

By merely increasing the specific impulse to 290, we can drop off one whole stage which brings our ratio down to 125 to one.

I cannot tell you in an unclassified session exactly where in this realm we are, whether we are at 3,125 or 125 pounds to 1. I will be glad to discuss this subject in more detail Friday, if you care.

One of the things that has been mentioned about solid-propellant rockets is the inability to control them—to cut them off, or to control the direction of thrust. I am not going to take the time, this morning, to discuss these next charts, but these do show some of the things that can be done to the solid-propellant rockets to control the direction of thrust, to cut the rocket off (cause a cessation of burning when you have enough velocity), or to modulate the thrust—in other words, to change the level of thrust at the will of some intelligence or some sort of command.

These are the three things that you ordinarily wish to do in certain types of vehicles. The next portion of this writeup discusses some of the means for doing this. I will not take the time to go into this in detail this morning.

We mentioned earlier the importance of thrust-to-weight ratio. I would like to bring up this subject again in relation to this age-old controversy of solids versus liquids. Each of them has its own special advantages and places where it should best be used. The simplicity, ruggedness, ease of handling, and instant readiness of solid rockets indicates that they should receive first consideration for most military applications. However, as things stand today, the liquid rockets still have a higher impulse, and for many applications this is a very, very important matter and produces a lot of payoff.

In order to get good mass ratios in a liquid rocket, you must load this rocket up with fuel, put a tremendous amount of fuel on board, to the point where the thrust-to-weight ratio is relatively low. In other words, in taking off within the earth's gravitational field, the g losses frequently are so high that the advantage of specific impulse is lost.

For this reason, one of the places where liquid engines can pay off in a tremendous way, where they can really outperform solids in a big way in reference to the present state of the art, is on the upper stages of space vehicles where gravitational field has very little effect. Under these conditions a liquid engine can be loaded with fuel to the place where the thrust to weight ratio is perhaps less than one, or even much less than one. Very high mass ratios can be obtained under these conditions, and correspondingly high velocities per burning of the stage can be imparted to the vehicle.

However, the solid propellent impulse is low compared to the liquid—and by the way I think I can quote some figures.

This material I showed you was basically hydrocarbon and ammonium perchlorate. The peak impulse available with this is around 250 pound seconds per pound. This compares with a figure quoted yesterday by Mr. Hoffman, I believe, of 273 pound seconds per pound for oxygen and petroleum hydrocarbon fuel.

However, this solid material is more dense. In other words, you can pack more of it in a given volume and frequently the greater density impulse also produces an advantage in the final engine, particularly here when you are operating in an atmosphere and drag becomes a major consideration—the atmospheric friction.

Mr. FULTON. Has there been any work done on that density problem?

Dr. RITCHEY. Yes, sir. You are talking about the solid field or the liquid?

Mr. FULTON. In the whole fuel field. I was thinking of some of the dense materials we knew that must be on some of the stars that weigh 200,000 pounds per cubic inch.

Dr. RITCHEY. It would be very nice if we had some of that material on earth, but I don't think anyone has ever produced it. We have to take, in the density problem, the conventional chemical materials and do the best we can with them. How to do the best we can becomes a very complex problem, but certainly there has been a lot of attention given to this matter.

The CHAIRMAN. The advantage of density, as I understand it, is that it permits the fuel to burn longer. Is that correct?

Dr. RITCHEY. The advantage of density is merely this: You can pack more material in terms of pounds into a given volume, into your fuel tanks, let's say.

The CHAIRMAN. And consequently the same size would burn longer?

Dr. RITCHEY. Or produce more energy, that is right, yes. With the same thrust it will burn longer—you can put it this way.

Mr. FULTON. Much less mass. Is the mass less?

Dr. RITCHEY. The main advantage here is cross-sectional area which affects the drag. The lower volume you can get, the lower cross-sectional area for a given energy, the less drag. Here again this is primarily of importance when you are operating within the atmosphere.

The CHAIRMAN. Just proceed so we can finish your statement. We want to hear it out.

Dr. RITCHEY. There is one other matter I would like to touch on briefly, and this is a matter of size. I am essentially in agreement with everything that was said yesterday on the relative advantages of the liquids and the other controversial issues, except for perhaps one thing. In obtaining a million to a million and half pounds of thrust from a liquid engine, you have to pump about 4,000 pounds of propellants per second. This is two different liquids that have to be pumped in the right ratio and injected into a combustion chamber. This is a Herculean task at the least. I am not willing to say that people can't make one that will develop a 10-million-pound thrust in a single combustor, but here again I think that pumping 40,000 pounds of fuel per second is an even more Herculean task.

In solid rocket technology, we mix and inject propellants into the combustion chamber at the rocket manufacturing plant. They are already there, and all we have to do is ignite them. The pumping problem is not present. For that reason, solid rockets have a capability, a fundamental capability, of developing higher thrusts without encountering the tremendous mechanical difficulties of pumping very large volumes of propellants against a high pressure head.

One of the troubles, of course, you run into, is this: a million-pound-thrust rocket that burns for a hundred seconds, whether solid or liquid, will weigh someplace in the order of half a million pounds.

This means, whether solid or liquid, that the propellants must be put into the system at the launching site.

One of the problems we have been studying—and we think it is quite solvable—in fact, a relatively easy problem—is a method of loading a very large, solid-propellant rocket at the launching site. With the development of this technology, there is no size limitation in the foreseeable future on solid rockets. There is no limit, real fundamental limit, on how big they can be made or how much thrust can be obtained from them.

Just a word about the company. I notice you asked the other witnesses questions about their operations. We actually have five rocket plants: The Reaction Motors Division at Denville and Rockaway, N.J.; the Elkton Division at Elkton, Md.; the Redstone Division at Huntsville, Ala.; the Longhorn Division at Marshall, Tex.; and the Utah Division near Brigham City.

We have about 7,000 employees altogether in our rocket engine business, of whom about 5,000, about the same as Mr. Geckler mentioned, are actually engaged in solid rocket work in one form or another.

Of our total business volume, I would guess in 1958 somewhere between $20 and $25 million were expended on what might be called research and development effort. Most of this effort was development. Very, very little of it went into what might be called advanced research, and I expected to be asked this morning how much we had spent last year on the simple problem of doing research on materials that might give specific impulse values above 260 pound-seconds per pound.

Mr. FULTON. You are asked now.

Dr. RITCHEY. We came to the conclusion we have probably spent in 1958 less than $100,000 on this particular problem, and it was not spent in an integrated attack on it. It was spent on a sort of an odds-and-ends basis, a little bit here and a little bit there.

The CHAIRMAN. That really presents something that we could very well look into, doesn't it?

Dr. RITCHEY. I agree.

The CHAIRMAN. I mean we, as a committee, could make recommendations in reference to that.

Dr. RITCHEY. This concludes my remarks, gentlemen. I thank you very much.

The CHAIRMAN. Well, it is an excellent statement, sir, and we appreciate being allowed ready reference to your material.

Mr. Teague?

Mr. TEAGUE. Doctor, in your liquid and solid fuels, what is the relationship between the total weight and your payload? What part do the fuels play?

Dr. RITCHEY. The total weight and the payload?

Mr. TEAGUE. Right.

Dr. RITCHEY. You can't make any definite statement about this because you have to look at the missile itself and what it is intended to do. Some of these things are artillery rockets. They are expected to go, let's say, 4,000 yards.

In these cases the fuel might be a very small portion of the total system, and the payload might be a very large portion of the total

system because it doesn't have to go very fast. As you put a requirement on it to go faster and faster, which essentially means farther and farther, then you try to optimize a system. In optimizing your missile system you usually do this by a number of different things, including reducing the payload itself.

As I pointed out here, in a single-stage or a multiple-stage rocket, usually if what the rocket is carrying weighs about one-fourth as much as the rocket does when it starts to burn, this is somewhere near optimum for maximum efficiency. So ordinarily you might say that the payload itself for optimum results should be right around 20 percent of the gross weight of a single-stage rocket.

The CHAIRMAN. Let met ask you gentlemen, all of you testified as to the liquid and the solid fuels. I would judge by listening to each of you that you feel that there is more future and greater possibilities in the use of the solid fuels, is that correct?

Dr. RITCHEY. I think we are in danger to generalize any place in this area. There is a place for solids and a place for liquids. There are jobs today that one can do very markedly better than the other. This is true of each of the different systems, both the solids and liquids.

The CHAIRMAN. You feel there is still room for a steam engine automobile and a gasoline internal combustion engine? What about the others? Do you disagree, or do you feel like the future is in the solid propellant?

Mr. MARTIN. Speaking for myself, Mr. Chairman, I would certainly agree with Dr. Ritchey, that in the present state of the art there is no clear-cut superiority either way. It is going to take a lot of development time to explore a great many areas that lie before us, and it may well be, as Mr. Geckler has said, that you will have the same relationship that you have between matches, which are a solid means of providing flame, or a cigarette lighter, which relies on liquid fuel. Which is better? I don't know.

The CHAIRMAN. What about Dr. Longwell? How do you feel?

Dr. LONGWELL. I think there is very little question that there will be a place for both of them. Solid propellants, I believe, will serve as a work horse. You will find them used all the way from Bazookas up to very large missiles like Polaris. There is very little question but what it will be used in such applications.

When you get into space flight, it is a very moot point at the present time. It looks as though it will probably be a combination of the two.

The CHAIRMAN. What about Mr. Geckler?

Mr. GECKLER. I think with regard to space flight, we don't know enough yet to see into the future which will be used the most. With regard to military applications, there has been a strong trend in favor of solids because of the simplicity and servicing. I think this trend will continue and persist, and solids will be utilized a great deal and a great deal more in military applications.

The CHAIRMAN. Our present problem, as I see it from all of you, is to increase the specific impulse of the material used and lighten the weight of the non-payload. Isnt't that it? Those two things are the major problems.

Mr. GECKLER. Yes, sir.

The CHAIRMAN. As we work on those two problems, we increase the efficiency of the rockets, the satellites or whatever we are producing, is that correct? Everybody agrees on that?

Is there any possibility in the development of rockets, especially large size, that we would change the contour or shape? When I say that, I am referring to the effects of making a drastic change in the fuel used. There is a possibility that—for instance you have a rocket in which you plan on sending up a man. I can remember when the first order was placed by the Army for three airplanes, I think they were over in Virginia, and they specified they should have the ability to fly 40 miles and at least 1,000 feet up, or something like that, and carry two men.

Is there any possibility in the foreseeable future that we would change the type of fuel or construction of rockets so much from what we have at this time that they would look as different as modern airplanes do in comparison with the early ones of which I just spoke?

Dr. RITCHEY. Mr. Chairman, I think that question can only be answered by the results of several programs in the research stage at this time. We don't know really for sure what is going to come out of these programs—they wouldn't be research programs, of course if we knew ahead of time what we were going to do. When I say "we" I am talking about industry in general.

We have to know what these new advanced fuels are going to look like, what their characteristics are before we really know how we are are going to go about using them in the best fashion.

The CHAIRMAN. Can we, as a Government, spend money properly, justifiably, in working to obtain different types of material that might be used for fuel, material that might have a much higher efficiency rating? Would such a program as that be justified?

Mr. GECKLER. I would like to answer that. For myself, I think it is very justified. What the propellant chemists have done up to the present time is to use available raw materials that the chemical industry supplied to make propellants. They have substantially exhausted the potential in the available raw materials. To get increases in specific impulse beyond what we are able to do today, will take the development of new raw materials on programs such as Mr. Longwell is associated with.

The CHAIRMAN. You think that that sort of program would be justified?

Mr. GECKLER. Yes, sir.

The CHAIRMAN. In going about a program of that sort, what would you recommend? That we simply use a regular setup of private industry plus what we have in the way of Government facilities for R. and D. programs, looking for new materials? Or do you have anything else you would recommend?

Mr. GECKLER. I think that covers about everything that is being done now. But as Mr. Longwell mentioned, the level, at least until recently, has not been high enough to achieve any substantial results. I think this is being expanded, and utilizing the proper methods, both industry and the Government.

The CHAIRMAN. Does anybody else have any ideas along that line? Dr. Longwell?

Dr. LONGWELL. You were questioning whether industry or Government would be the best place to do this research. I think if we wanted to do something quickly, and if you surveyed the scientists that were available to be transferred to this work without taking them off of other important defense work, you would find a great many more of them available in industry.

This is because, as a nation, we have been very advanced in chemical research. The chemical companies have been very aggressive and have put a large fraction of their money into research and have built up a large and very highly skilled staff.

So they have a big organization and many trained scientists. The Government laboratories also have them, but by and large they are already on the kind of problem you referred to.

The CHAIRMAN. So that does offer some advantage. That is what you mean?

Dr. LONGWELL. Yes, sir.

The CHAIRMAN. What do any of you wish to say in reference to the suggestion contained in the bill that has been introduced, to add to every contract for scientific development, 10 percent additional to be used solely for basic research?

Dr. RITCHEY. May we stand up and cheer?

Mr. GECKLER. I would be most emphatically in favor of it.

The CHAIRMAN. Do you think it would accomplish results and that we would be justified in spending the taxpayers' money that way?

Mr. GECKLER. I think it would stimulate invention among private contractors in a way I couldn't imagine could be stimulated any other way.

The CHAIRMAN. Too, if you had a contract for the development of propellants, wouldn't it be natural if they gave you 10 percent more for basic research, that you could use, for instance, in developing new types of raw materials, whereas to make it efficiently on a negotiated or open bid with the Government for furnishing that propellant, you would have to cut your figures straighter to the line?

Isn't that right, and therefore it would not leave you the reserve for this basic research? Is that correct?

Dr. RITCHEY. I would like to make a statement, Mr. Chairman, in this regard. One of the difficult things in the research programs in the past has been the necessity for supervision—I will say Government supervision, since these are essentially Government plants—which usually takes the form of requiring you to make such a detailed work plan before you start the job, that you actually have to do your research project before you ever get the money and get the contract started. In other words, you write out the plan predicting what you are going to do, you go in the laboratory and try to do it, you finish up and write a report on it. This system does permit close supervision, but it is very inhibiting in permitting the exploration of side issues that continue to come up and the exploration of good ideas that people may have as they work on the job.

To companies like Mr. Geckler's company, Aerojet-General Corp., and my company, the Thiokol Chemical Corp., and also to Hercules in their rocket business, this research is our lifeblood. If we don't do a good job of it, we will be out of business sometime in the not-too-distant future.

For that reason I believe that you can depend upon this type of organization to spend the research money very effectively without very close supervision.

The CHAIRMAN. In other words, if you don't do any research, you are not going to progress, and you will eventually lose completely out; is that right?

Dr. RITCHEY. That is right. If we don't do research, and if we don't do a good job with the money we do get for research, we will be out of business. So there is an automatic built-in control on this problem.

The CHAIRMAN. I don't want to take any time longer here in questioning all of these witnesses because we have about 50 minutes left. I am now going to open it up to questions by the committee. Does anyone have a question?

Mr. FULTON. I just have a comment. I will put in the record at this point a copy of the resolution I was working on for several weeks and have come up with a combined basic and applied research and development program in NASA, the National Science Foundation, and the Department of Defense, in the fields of fuels and propellants, as well as the structure, engines, and weighting materials. Some of us have been interested in that field and I began to work on that.

I likewise will pass to the other members of the committee on questions this morning.

(The resolution referred to is not available at this time because it is still under revision by Mr. Fulton.)

The CHAIRMAN. Any further questions?

Mr. VAN PELT. It is very academic, but I have heard so much about this countdown and have heard the countdown. I am wondering what the reason is for it, when they are getting ready to fire a missile?

Dr. LONGWELL. I think it is primarily a technique for coordinating the activities of a number of people, the ones that are participating in it. You will find that one person is supposed to do a certain thing when you reach five seconds, for example. He pushes a button or turns a switch. So they have this countdown going on over a PA system, and it coordinates the timing of all these various people that have to perform this intricate operation.

Mr. VAN PELT. Do they reverse the count when something has gone wrong?

Dr. LONGWELL. I have never had that happen.

Mr. VAN PELT. I think it happened with one failure I saw down at Cape Canaveral. They came back and then started over again. What do they use for ignition, either on the solid or liquid fuel?

Dr. LONGWELL. In the solid fuels they ignite electrically with a hot wire a little charge of powder of some sort that spreads to a larger charge that is capable of igniting the whole surface. I am not familiar in detail with the liquid ones.

Mr. GECKLER. They utilize in many instances solid propellant igniters.

Mr. VAN PELT. That is all, Mr. Chairman.

Dr. RITCHEY. Something like this, almost [illustrating].

The CHAIRMAN. Mr. King.

Mr. KING. I would like to pursue this matter of timing, the time that it takes to discharge a rocket, launch it. I have this practical

problem in mind. We are trying to maintain the balance of power, or superiority of power, over Russia. We have declared that we will never launch ICBM's as aggressors. We will not be the first to launch. We will use them only when they launch first.

Our problem is purely one of timing. They would know where our installations are. They could launch ICBM's with the idea of knocking our installations out of action completely. Therefore it follows that we would have to get our ICBM's in the air between the time that we are apprised that their ICBM's are on their way to us, and the time they get here, because if we wait until they get here we are too late. They are destroyed.

So we have what—just minutes to work in, don't we? What about our problem of timing here? The liquid propellants, as I understand it, take quite a bit of time, don't they? You don't have these ICBM's all stored and ready to go because the liquids are dangerous. They are cold. They have to be stored in special tanks. Is that not correct?

Mr. GECKLER. The presently used liquid propellants.

Mr. KING. So you are talking about hours and hours, rather than minutes. So as things are now, we are not in the running. Isn't that right? Our installations would be completely destroyed before we could get the liquids into the tanks and our missiles fired.

Am I right on that? So our problem is really one of reducing hours down to minutes, or else we are not in the running. Is that where the solid propellant comes in and performs its great role—the fact that your countdown time can be reduced from hours to minutes? Am I correct on that? Could one of you explore that for a minute?

[Ed.: R. & D. launchings take hours; operational launchings are expected to take 15 minutes.]

Dr. RITCHEY. I believe this reasoning you have gone through here is exactly parallel to the reasoning we went through in justifying the fundamental need for the Minuteman ICBM program.

Mr. KING. Which of course is still on the drawing boards, isn't it? It is being pursued.

Dr. RITCHEY. I think that any discussion of schedules is classified.

Dr. LONGWELL. I think in the case of the liquid rockets, though, it is possible to substitute propellants that can be stored, say gasoline, and you might say nitric acid or some other oxidizer. It would have somewhat less performance than the present ones, and it is also possible to improve these by having a material that can be stored in the tanks just like you would in your automobile, it is then possible, in principle anyway, to start them quite quickly.

I think they will always be a little slower than the start you can get on a solid propellant, but from a technical viewpoint it seems possible to develop liquids so that they can start quickly. The present ICBM's, though, are not that type. They have to be loaded with liquid oxygen. This is a matter of development, to get what they call a storable liquid propellant system.

Mr. KING. Titans and Atlases still take hours to get off the ground, don't they?

Mr. GECHLER. Not all of the time consumed in the countdown is attributable to the propulsion system. There are complicated guidance systems that require adjustment, and so forth. So it is not all the propulsion system.

The CHAIRMAN. Mr. Fulton?

Mr. FULTON. Could I ask the gentleman from Hercules Powder Co. what has been done on the research and development for explosive charges for separating the various stages of vehicles?

Mr. MARTIN. I would say this, Mr. Fulton. The separation problems have not been a serious part of the whole technology. We, along with a great many other manufacturers, make igniters and actuators, as they are called, as a class, various types, which involves putting relatively small amounts of fairly conventional explosives in the device to be actuated and providing a means for detonating them when required.

It is the same type of unit that is used in ejecting pilots from jet planes and jettisoning spare gasoline tanks and in jet engine starters for aircraft—small packages of power. They don't represent any large problem at all.

Mr. FULTON. I was at Cape Canaveral when there was a failure of separation of two stages. Obviously when there is that failure of separation there is a tremendous loss in research and development, as well as in time. So my comment is, what can you put in the record later, any of you, as to what research is being done in that particular field because I have heard none in the presentations so far.

Dr. RITCHEY. May I make a comment in this regard? In this session you are talking primarily to rocket engine people rather than to missile systems people. I believe the method by which a missile is put together, what makes it fly, how it separates, how it is guided, what kind of a package it carries, all these things belong to the missile systems question and not particularly to the propulsion question. In other words, we make the engines, someone else puts them on the airplane, if you want a simple analogy.

Mr. FULTON. Isn't Mr. Martin of Hercules Powder Co. the one to ask about explosive charges on a separation stage?

Mr. MARTIN. I think your question is a proper one as far as the device itself is concerned. I think Dr. Ritchey has a point in the final assembly. In other words, no matter how good an individual component is, if it isn't assembled properly, it is like a light bulb—if it isn't screwed in the socket, it just never burns when you flip the switch.

Mr. FULTON. Could your company put in the record later at this point without taking the time now, a comment of some sort of assembly on the research and development in this field of the explosive charges used in the various separations of missile stages?

(The information requested from Mr. Martin is as follows:)

So far is I know, there has not been a great deal of specialized research and development on new types of explosive charges used for the separation of missile stages. Certainly Hercules has not engaged in any such research work, and so far as I know, only conventional types of explosives in specially adapted devices have been used.

The CHAIRMAN. Mr. Daddario.

Mr. DADDARIO. Dr. Ritchey, in answer to some of the questions by the chairman you seem to indicate that the present system is too confining insofar as Government activity in your field is concerned.

Dr. RITCHEY. So far as research activity is concerned.

Mr. DADDARIO. Then you go from there to something I don't quite understand. You say because the lifeblood of your industry is re-

search and development, there is therefore an automatic, built-in control. How could you relate that from one company to another? Why should your company have the same type of built-in control in it as the companies of these other gentlemen, each one of them having different management approach? Couldn't you open the door in this manner to a great deal of waste which would be comparable to that which might exist now through this supervision?

You just can't go from control to no control, can you?

Dr. RITCHEY. The built-in control I was discussing is simply this: In Hercules' rocket operations, Aerojet-General, which is primarily in the rocket business, and Thiokol Chemical Corp. is primarily in the rocket business, if we do not do a good job of research, we won't be in the rocket business very long, so we won't have any more funds to spend. This is where the built-in control comes from that I was discussing.

In other words, the motivation to do a good job within our own management is very intense. There is no outside motivation that can be any more intense than the motivation to spend research money effectively.

Mr. DADDARIO. I understand that. And yet it doesn't have any limits. There has got to be, does there not, some kind of a limitation to it. You just can't say that each company, because it is its lifeblood, ought to be able to have as much money as it may need to spend in any way that it possibly may desire in order to accomplish a certain end. You may be the kind of a fellow who runs his company and make a few men do it, and somebody else may run it to accomplish the same end, because the Government was paying the funds, and be all over the lot and hire hundreds of people to do the job to get this experiment in a successful solution.

Dr. RITCHEY. I never had any intention of suggesting that there be no limitation on the amounts. My remarks were primarily directed along the line, how do you control how it is spent—what money you do get—how it is spent within the organization. Obviously it would not be proper for the Government to give the companies in this field a blank check to do research. I am not suggesting this at all.

However, I do think the volume of research could be increased tremendously over what it has been in the past with the effect hardly being felt in the total overall budget.

Mr. DADDARIO. The thing that bothers me is the same thing that bothered me yesterday when you thought that duplication was in fact competition, and that you subscribed the normal functions of the process of the economy as it works to this kind of an operation, where things will balance off each other.

I think you get into that same type of a fallacy in this business of built-in controls. I think that when you make a suggestion that there ought to be some kind of limitations to it to fit into this particular picture, I think it ought to have some kind of incentive. It ought to have some kind of a reward as a result of something you may do within a certain budget.

We touched yesterday on such things as proprietary rights. Perhaps if you do something in a certain manner within a certain budget, then you could perhaps control this rather than have it spread throughout the overall industry.

This seems to me to be the kind of limitation that you have to add to this kind of a program since you don't have normal competition working its way in this research and development field. Don't you think there has to be something of that type added to it?

The CHAIRMAN. Following that line of questioning, of course, the basic research has to be done if we want to get ahead. That is correct, isn't it? It seems to me, the question is: Who would be the better one to do the basic research? Would it be a man or a company which has a contract to produce fuel, and is it to his interest to develop a more efficient fuel? Would his concern be better to do the basic research than someone who perhaps is not in that business?

That would be one thing. What do you think of that?

Dr. RITCHEY. The economic motivation, in other words, the desire to do a good job in order to stay in business is a very strong one, whether you are talking about research in a field that ends up with a Government product, or research in a field that ends up with a commercial product.

There is always this strong motivation within the people who are manufacturing an item and selling it, to do a very good job in the research end of their operations.

The CHAIRMAN. Do you mean by that, to produce a better product? Of course they are going to be recognized for having done a better job. If the research, then, is available in the way of some funds, limited funds, under proper supervision, of course, and they reach satisfactory results, it will inure to the benefit of the Government which is the one that uses most of this product. That is right, isn't it?

Dr. RITCHEY. Yes.

The CHAIRMAN. Have you any point to argue? What is your thought along that line—research? Have you any further suggestion or ideas along that line?

Dr. RITCHEY. As far as the general administrative side of it is concerned, this principle that you mentioned a while ago, of allocating a certain percent of total business volume to research, I think this is a very, very sound approach to the matter, and it is exactly the way the matter is done in industrial organizations. Usually some sort of management decision is made as to the percent of the sales dollar that is put back into the research operation. I would be very, very happy indeed to see the same principle applied to Government development and manufacturing business.

The CHAIRMAN. Of course I think that is one of the mistakes we have made in this country. We have not pushed basic research. The Germans took basic research. We made discoveries, probably, new inventions. The Germans went ahead with basic research and developed the V–1 and V–2 rockets, they developed the jet plane and those things. They did it because of their basic research program. Isn't that right?

Dr. RITCHEY. That is correct. The same thing is true in this country. The development of nuclear energy came from very fundamental experiments that were done, and done at the time, only because of laboratory curiosity. In fact, you can point to almost any major development and trace it back to the point where someone merely

asked himself what appeared to be a useless question at the time, and went into the laboratory and found an answer for it.

I believe that Mr. Kimball mentioned yesterday the discovery of electricity. This was originally done by poking a dead frog with a charged wire and watching the muscles twitch, something that no grown man, you would think, would waste time with, and yet it eventually ended up in the tremendous electrical industry.

The CHAIRMAN. Does anybody else have any ideas along that line? Dr. Longwell?

Dr. LONGWELL. You asked a question on the best place to do certain kinds of research. If we might just take chemical research as an example. My feeling is the best people to do it are the ones whose primary interest is in that field. If you ask an engine manufacturer to do chemical research, I would think this would be a secondary interest to them, compared, say, to one of the chemical companies, Hercules, or Du Pont or somebody. You will find that the chemical companies are staffed, and their whole objective is aimed toward that. So they will generally have better people lined up and available for it.

I think in research ultimately the results come down to the quality of the people that can be put on the work. So I think generally if you have companies or governmental laboratories that are organized, and their thoughts are aimed toward a certain direction, the work in that line would best go with them, rather than to try to get somebody who is interested in machinery, for example, to think about something else. Of course this applies to other fields.

The CHAIRMAN. Do you know how the Germans handled their basic research program?

Dr. LONGWELL. I know some specific cases. Here again my own field is in chemical research, so I will use that as an example. I. G. Farben was a company that made a great many contributions in chemical research. Their technique in many cases was to hire one or more extremely good chemists, give them half a dozen assistants, and give them 5 years and let them work. These people were familiar with what was wanted by the company and were allowed to devote themselves to their field of interest.

One can point to several very outstanding developments. Perhaps I needn't go into specific individuals because I doubt that they would be familiar, but this turned out by getting very good people and letting them work, trying to discover new things, they got very good results.

The CHAIRMAN. They developed the color industry, didn't they, the dye industry?

Dr. LONGWELL. Yes. This would be an example of how they did it. They were also leaders in finding catalysts for converting one chemical to another, and they made a great many discoveries in synthetic rubbers.

The CHAIRMAN. That system worked with them very well, didn't it?

Dr. LONGWELL. Yes.

The CHAIRMAN. It was done not by the government, but by private industry.

Dr. LONGWELL. That was a case of private industry doing it. The universities were also always very strong — technical high schools as they call them there. The people there got quite a bit of financial support. The professors there were the ones that rode around in limousines, the top ones. This was a career to really strive for, and they developed very effective teams, some professors had a large number of assistants, and there again they were able to concentrate on developing the most out of their field.

The CHAIRMAN. Did they get the professors from the universities or did they pick them up from industry, or how did they acquire them?

Dr. LONGWELL. I think a typical career would be that a young student who was found to be extremely outstanding would be offered a position to stay on as an assistant or some other staff position in the university. If he were successful, he would make this a career. This was a very attractive career and they were able to pick the cream of the graduating classes that way.

The CHAIRMAN. Mr. Anfuso.

Mr. ANFUSO. Following up Mr. King's very astute observation: Is consideration being given to protecting our installations from ICBM attack? I am not referring to the Nike-Zeus. Are any other systems being studied to protect these very expensive installations?

Dr. LONGWELL. I was reading an article in Aviation Week about their plans on handling the Minuteman ICBM. You may have read the same thing, where the plan that was published was in effect to have a cylindrical hole going way down into the ground and the rocket would sit down in this hole. There would be a very thick concrete slab that was on the top that would be rolled back when they wanted to fire.

These would be widely spaced in remote areas of the world.

Mr. ANFUSO. In other words, building tunnels. Is that something like that?

Dr. LONGWELL. Yes. They would be largely vertical, I believe.

Mr. ANFUSO. Would the covering on top be sufficient, you think, to protect the installation?

Dr. LONGWELL. I can't give any real expert background on this. From what I read, they feel that there is no protection against a direct hit from a hydrogen bomb, but they would require a great deal more accuracy on the part of the enemy because a hit off to one side would probably not destroy the thing.

Mr. ANFUSO. I don't foresee a direct hit because that is almost an impossibility. But say a hit within a mile. Would you think striking within a mile area would destroy that installation?

Dr. LONGWELL. Just to make a guess, I would guess it would be possible to protect against a miss of one mile.

Mr. ANFUSO. Do you think, Doctor, that that is something that we certainly ought to look into very quickly?

Dr. LONGWELL. I think that it is being very carefully considered by the military people, but I also believe it would be a very interesting subject for you people to familiarize yourselves with.

The CHAIRMAN. Will the gentleman yield?

Mr. ANFUSO. Yes.

The CHAIRMAN. Is the Doctor referring to nuclear explosions?

Dr. LONGWELL. Yes.

The CHAIRMAN. You think a miss of a mile would be protected under that arrangement?

Dr. LONGWELL. This is a guess on my part. I think it would be possible.

The CHAIRMAN. You are an expert in explosives. All of you are. That is the reason we want your opinions here. We seldom have an array of experts in explosives like we have this morning.

Mr. ANFUSO. I think we all realize the importance of that because if we are not going to strike first, as Mr. King says, our installations are going to be destroyed, and then we have no power of retaliation. So it occurred to me that immediately we ought to devise some method of protecting these devices, these installations.

Would you agree, Doctor?

Dr. LONGWELL. Yes, I agree. I might just add one other technique that is being considered, that is, having mobile bases so they never know for sure where they are. This is very good protection. The Polaris is proposed for that. It is in a submarine. The submarines cruise around so they would never be able to wipe them out in one instant.

Mr. ANFUSO. If you received a 15-minute warning, for example, how fast do you think you could travel and move that installation in 15 minutes?

Dr. LONGWELL. I don't think you could move it very much in 15 minutes. You would just have to assume that the Russians didn't know where they all were at any one time.

Mr. ANFUSO. I don't think we can assume that. I think we can assume that they pretty much know where—they certainly know where Cape Canaveral is. They certainly know where our base is in California and Texas.

Dr. LONGWELL. It is much harder with a movable one, of course, particularly with a submarine that can't be seen.

Mr. ANFUSO. I am no scientist, but I was wondering whether maybe an electrical device could be invented that would divert the missile, some kind of an electrical current would arise to divert the missile, that is, the striking missile. Is there any possibility along those lines?

Dr. LONGWELL. I don't know of any.

Mr. ANFUSO. Is it within the realm of possibility?

Dr. LONGWELL. One never wants to say anything is impossible, but nothing occurs to me that would approach this sort of a system.

Mr. ANFUSO. I will yield.

Mr. TEAGUE. I heard a remark last night that we need freedom of the press in this country, but sometimes we need freedom from the press. I think that is probably true as to the location of our missile sites and that kind of thing.

Mr. ANFUSO. If not some electrical device, perhaps—in other words, I am thinking of something that when you see a missile coming over the atmosphere in a particular locality, it would divert that missile away from that installation. Is that within the ingenuity of man to devise?

Dr. LONGWELL. It sounds very difficult to me. I wouldn't say we couldn't do it a hundred years from now.

Mr. ANFUSO. So far, your best method would be then this underground covering.

The CHAIRMAN. Any further questions?

Mr. Ducander, you have an announcement?

Mr. DUCANDER. Yes, sir, you wanted to call to the attention of the members the World Congress of Flight which will be held in Las Vegas from April 12 to April 19. If the members would like to go, there is an interesting discussion on the 16th, Missile Management; on the 17th, the Space Age Conference, and we can arrange transportation to leave on Wednesday, April 15 at 9 o'clock in the morning, arriving at Las Vegas at 4 p.m., and to depart Las Vegas at 9 o'clock in the morning on Sunday, April 19.

The CHAIRMAN. I would suggest you wait—it is so far off——

Mr. DUCANDER. Mr. Chairman, the Air Force is most anxious to find out how many members want to go so they can make hotel reservations.

Mr. ANFUSO. There will be the Easter recess, Mr. Chairman.

The CHAIRMAN. That is true. They told me yesterday they would have flights going from time to time. I think the first would go on Sunday, I believe they said. Then there would be a flight Wednesday coming back.

Mr. DUCANDER. As a matter of fact, they will arrange the flight for the committee's convenience.

The CHAIRMAN. I hope all the members will bear that in mind. Those that can arrange to go, I think it is in line with the work of this committee. They should bear it in mind.

I want to announce the program, too, at this time, for tomorrow. We have Mr. Thomas F. Dixon, chief engineer of Rocketdyne, North American Aviation, Inc., accompanied by Dr. Stanley V. Gunn. We have also as a witness Dr. Arthur Biehl, vice president and technical director of the Aerojet-General Nucleonics Division. We have Mr. William J. Reinhardt, head, technical planning section of Reaction Motors of Thiokol Chemical Co., with Mr. John J. Newgard, project engineer, nuclear propulsion. That is our program for tomorrow.

I would like to ask a few more questions now. Dr. Longwell, in your statement you said this, and I think it is a very, very pertinent statement to make:

> Ultimately the choice of propulsion systems for space flight and for military missiles will be determined, not by the comparisons and opinions that we have today, but on the performance of these devices when full advantage is taken of the materials and techniques that the laws of nature make available to us.

In other words, you are coming back to that same proposition which is basic research. As you open up your basic research, that gives you greater opportunities and you adapt your plans accordingly. That is substantially what you have in mind.

Dr. LONGWELL. Yes. There was one other angle I had in mind there, and that was the competitive angle between us and the Russians. I think as time goes on we will find the facts; we will find out what materials and techniques are best. To have an advantage, we want to find them first.

The CHAIRMAN. What are the Russians doing in the way of developing propellants? Can you give us any information on that? Can anybody here tell us that? Do we have access to any knowledge

that they have in the development of their propellants? Our industry doesn't have anything on that?

Dr. LONGWELL. No.

The CHAIRMAN. So we are developing our own propellants without any reference to the Russian developments. Do they use liquid or solid propellants?

Dr. LONGWELL. The publications I have seen, I believe, indicate a liquid propellant in their large engines that they have been using to launch space vehicles.

The CHAIRMAN. So they are still using liquid propellants. I have no further questions. Anybody else?

Mr. KING. One more question.

The CHAIRMAN. Mr. King.

Mr. KING. After your solid propellant has been completely consumed, is there a residuum left over of consequence?

Mr. MARTIN. No, not that I am aware of; not an appreciable residue.

Mr. KING. I was going to suggest if there was, then, that would also constitute a factor that would diminish the efficiency of the machine.

Mr. MARTIN. Not if your design, as Dr. Ritchey has mentioned, is efficient, and the configuration properly worked out.

Mr. KING. So you are left with an empty shell.

The CHAIRMAN. I think I asked whether or not anybody had any information in reference to nuclear propellants that they would like to give us this morning. Is there any expert on nuclear propellants here?

If there are no further questions, then——

Mr. MOELLER. Mr. Chairman, may I ask one?

The CHAIRMAN. Surely.

Mr. MOELLER. I wanted to ask Dr. Ritchey yesterday: What is the Government's investment in Thiokol?

Dr. RITCHEY. I thought somebody was going to ask me that.

Mr. MOELLER. I am glad you came prepared.

Dr. RITCHEY. About $60 million. This is not in Thiokol, I want you to understand. This principally is in two plants that are Government owned and operated by my corporation. This is the best estimate I can make. Actually these plants were originally designed and built for a completely different purpose during World War II and were modified for the job that we are doing with them. This figure is probably too high, based on present replacement value, but is somewhere near reasonable, let's say, for what they originally cost, plus the modifications that went into them.

The CHAIRMAN. You are merely operating the plants, aren't you?

Dr. RITCHEY. These two plants; yes, sir. The two plants we are operating are the one at Huntsville, Ala., and the one at Marshall, Tex. The other two plants we own ourselves, principally—three actually, the Reaction Motors plant, the Elkton plant, and the Utah plant.

The CHAIRMAN. When you move out of those plants, do they belong to the Government or to you?

Dr. RITCHEY. The ones we are operating?

The CHAIRMAN. Yes.

Dr. RITCHEY. They belong to the Government.

The CHAIRMAN. So actually the Government investment is in the plant, and you are operating them?

Dr. RITCHEY. Right. In our other plants there is some Government investment there, but it is principally in severable equipment which the Government can pull out at any time.

Mr. MOELLER. But they claim title to it?

Dr. RITCHEY. That they keep the title too; yes, sir, and they may claim it at any time.

Mr. MOELLER. Isn't the same true with Esso?

Dr. LONGWELL. Yes, sir. The Government in our contract has bought certain instruments and special equipment which is portable.

The CHAIRMAN. I wanted to ask, too, about Hercules. Does Hercules have the same arrangement with the Government?

Mr. MARTIN. Yes, sir, under our contract at our Utah plant, certain of the instrumentation and equipment used in the manufacture of a specific missile will be owned by the government.

The basic plant itself, the buildings, some of the basic production equipment, and the vast majority investment, will be Hercules' own money.

The CHAIRMAN. Then when you move out of the plant, or when you give up the equipment it belongs to the Government?

Mr. MARTIN. We would never move out of this plant, Mr. Chairman. It is tied in with a commercial explosives facility of our own and was merely an addition. So it is planned as a permanent plant unless the whole program folds up. Of course we would have to find something else to do with it. But the equipment itself belongs to the particular service for whom we are working at the time.

The CHAIRMAN. It could remove it?

Mr. MARTIN. Yes.

The CHAIRMAN. What about Aerojet-General Corp.?

Mr. GECKLER. It is similar to what has been defined. Approximately 60 percent of the facilities, as I recall, are owned by the Government. About 40 percent are owned by Aerojet. This is in the total Aerojet-General Corp.

The CHAIRMAN. Is the Government materiel subject to being removed there—Government equipment?

Mr. GECKLER. It is subject to being removed. In certain instances it is on land that has been deeded to the Government or they have an option for it.

The CHAIRMAN. Do you have a contract to operate that equipment?

Mr. GECKLER. Yes, sir.

The CHAIRMAN. We want to thank all of you gentlemen for coming here this morning. I think you all had excellent statements. The committee appreciates it very much.

If there is no further business, the committee will recess until tomorrow morning at 10 o'clock.

(The following letter to the chairman is inserted in the record:)

ASSOCIATION OF AMERICAN RAILROADS,
OPERATIONS AND MAINTENANCE DEPARTMENT,
Washington, D.C., March 20, 1959.

Hon. OVERTON BROOKS,
Chairman, Committee on Science and Astronautics,
House of Representatives, Washington, D.C.

DEAR CONGRESSMAN BROOKS: This statement is presented on behalf of the Association of American Railroads and is offered to clarify and rebut some parts of the statement made by Dr. H. W. Ritchey, vice president and technical director, rockets divisions, Thiokol Chemical Corp., before the Committee on Science and Astronautics on March 17, 1959.

The Association of American Railroads includes in its membership practically all class I railroads in the United States and Canada and represents 85 percent of the combined railroad mileage of the two countries.

The Association of American Railroads did not appear before your committee at the time of hearing and we respectfully request that this letter be included in the record.

Dr. Ritchey stated:

"Current physical size limitations of large solid propellant rocket motors are generally agreed to be approximately 80,000 pounds total weight and 12 feet in diameter. The 80,000-pound weight limitation is established by the load-carrying capacities of highway and railway bridges.

"The 12-feet diameter limitation is established by the clearance of underpasses and obstructions along right-of-ways. This size limitation can be overcome easily by use of special means of transportation, such as airships. This method of transportation would be applicable, of course, for peacetime applications within the continental limits of the United States. The limit to the size which would be lifted in this manner would be established primarily by the size and number of available airships.

"Since transportation facilities are the only size limitation on large solid propellant rocket motors, this can also be overcome by on-site motor manufacture. In this instance the motor case or chamber could be fabricated in sections and transported to the manufacturing site for assembly.

"Propellant would be loaded into the motor by a mobile casting method which has been studied in great detail by the Thiokol organization and is believed to be not only feasible but very desirable.

"By this method the size of solid propellant rocket motors is unlimited. Such motors would be launched from the manufacturing area because of transportation limitations. Extremely large motors of this type, even significantly larger than the 300,000-pound example discussed previously, would be ready for launch at the exact instant that the sun, moon and the planets are in their most advantageous relative positions."

As an indication of the carrying capacity of railroad freight cars attached is copy of the latest edition of the Official Railway Equipment Register, Volume LXXIV, No. 3, of January 1959. Over the past several years the tendency has been to increase the capacity of railroad freight carrying cars. The railroads were interested as it gave them increased capacity with fewer units. The shippers were insistent on this development because of material-handling costs and demurrage in cases where cars were delayed. Today it is practically standard to build cars of 140,000-pound capacity. As reference I would point out the New York Central cars on page 118, Pittsburgh and Lake Erie on page 138, Erie on page 174 and others. Particular reference is made to Pennsylvania Railroad cars shown under "Class F-Flat Car Type" on page 94. This listing includes cars of 500,000-pound capacity which are offered in interchange.

This Association recently conducted a clearance study on several railroads to develop the possibility of moving missile shipments 17 feet 10 inches high and 13 feet 6 inches wide. We were pleasantly surprised that very little work would be required to accommodate such shipments.

From the above it is clearly indicated that weight and size restrictions referred to by Dr. Ritchey, so far as railroads are involved, are in error and should be clarified.

Respectfully yours,

R. G. MAY, *Vice President.*

(Whereupon, at 11:47, the committee recessed, to reconvene at 10 a.m., Wednesday, March 18, 1959.)

SPACE PROPULSION

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., Wednesday, March 18, 1959.

The committee met at 10:05 a.m., in room B–214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. The meeting will come to order.

This morning we have several witnesses. We have them in groups. We have Mr. Laurence L. Waite, senior vice president for engineering and planning, North American Aviation, Inc.; Mr. Thomas F. Dixon, chief engineer, Rocketdyne, North American Aviation, Inc.; and Dr. Stanley V. Gunn, manager, nuclear propulsion projects, Rocketdyne, North American Aviation, Inc., in one group.

Then in the second group we have Dr. Arthur Biehl, vice president and technical director of the Aerojet-General Nucleonics Division in California.

In the third group we have Mr. William J. Reinhardt, head of the technical planning section, Reaction Motors Division of Thiokol Chemical Co., and John J. Newgard, project engineer of nuclear propulsion, Reaction Motors Division, Thiokol Chemical Co.

My thought is, we can proceed with the first group first—Mr. Waite, Mr. Dixon and Dr. Gunn. We have you all at the head table, do we?

Mr. Waite, I think you have a statement, don't you?

Mr. WAITE. Mr. Chairman, I think to save time we would like to have the chief engineer of Rocketdyne, Mr. Dixon, read his prepared statement.

The CHAIRMAN. Mr. Dixon.

Mr. DIXON. Mr. Chairman, I have a prepared statement and I would like to summarize this from charts, if it is permissible.

The CHAIRMAN. All right, sir, we will be happy to have it.

STATEMENT OF THOMAS F. DIXON, CHIEF ENGINEER, ROCKETDYNE, NORTH AMERICAN AVIATION, INC.

Mr. DIXON. In the last several days you have heard that chemical energy obtained from liquid rockets can give you performances in the order of 450 seconds impulse. That is pounds thrust per pound of propellant per second.

We would like to discuss this morning another energy level for propulsion. Since the concept of fission reaction, the use of this fission process has been considered by engineers for propulsion. The concept is quite straightforward that we would like to discuss, such as the energy released from a reactor, fission reaction of uranium 235, and then the transfer of this heat to a fluid from cold temperatures to a hot

gas. Then from the hot gas we expand from subsonic flow to a supersonic velocity. This results in a thrust.

The nuclear rocket concept that we will discuss is very similar to the chemical. Here is a schematic of such a device. (See p. 133). It is very similar to the chemical in that it has all of the major components except the combustion process that takes forth in the chamber is replaced by a reactor, a heat source. Essentially it has the propellent tanks to contain the propellant. It has a pump and a turbine to force the propellant into the reactor, and in this reactor, of course, the heat is released to the fluid and then expanded at supersonic velocity.

The main advantage of such a system is that from the reactor we can obtain very high temperatures.

Mr. MILLER. What type of fluid do you use?

Mr. DIXON. The type of fluid that is most adaptable for this system and to give high performance is a low molecular weight liquid such as liquid hydrogen. By the combination of the highest temperature and liquid hydrogen we can result in a very high performance.

As you can see here, we have the pumping system, we can also exhaust the turbine gases which we use for control. In this case certain elements in the reactor can permit low temperature gas that can return back to the turbine. In this case of a concept, the whole system is in bootstrap with respect to this operation.

Here is a picture of a typical nuclear rocket in space. (See p. 135.) It essentially looks very similar to the chemical rocket. These are the tanks above here. In this case this is the power plant package. You can see where the reactor is located. In this case the turbopump that forces the propellants through the reactor is assembled close to the throat of the chamber, and also this is the nozzle for exhaust of the gas.

The CHAIRMAN. You are changing the design just a little, aren't you? It has flattened out a bit.

Mr. DIXON. Yes, in this case, it is more compact than before.

Mr. MILLER. If the gases give you the thrust, are they contaminated? Do they just pass through the reactor and pick up the heat?

Mr. DIXON. I will discuss that. I believe I can answer that question later.

Mr. MILLER. All right.

Mr. MOELLER. Could you give us the weight relationship? Is the weight also cut down?

Mr. DIXON. The weight relation of this power plant package in most designs has a thrust-to-weight ratio of approximately 30. The liquid chemical engine has a thrust-to-weight ratio of about 100. So the nuclear rocket is somewhat heavier, but due to the fact of the high performance we obtain from this system, which is a result of the high temperature of the gases and the low molecular weight, we have about 300 percent improvement in performance over the chemical rocket.

This can result in design of certain missiles for space approximately up to 90 percent decrease in thrust or a decrease in the weight of the missile, depending upon the specific application. (See p. 136.)

Let us discuss some of the applications that show the advantages——

The CHAIRMAN. Let me ask you first about the 300 percent. Explain what you mean by that. Is that much greater thrust, that 300 percent more thrust?

Mr. DIXON. I can explain it this way: The chemical rocket has a specific impulse of around 400 seconds. That is four hundred pounds of thrust per pound of propellant going through the rocket system per second. The nuclear rocket has approximately 1,200 seconds at its upper temperature level which is about three times the performance.

The CHAIRMAN. Is the nuclear mass burned out at that point?

Mr. DIXON. No. In this case the nuclear rocket's reactor transfers heat to the fluid and brings the temperature of the gas up to 400° to 500° Fahrenheit.

The CHAIRMAN. And the heat is exhausted at 1,200 seconds?

Mr. DIXON. That is right. Then the heat flows through the nozzle and is exhausted at supersonic flow.

With this example of the advantages of the nuclear rocket, we have a mission. This mission is a very ambitious mission to take around approximately 50 tons from the earth's surface to the Mars orbit and then return to the earth orbit. This is a large payload for an interplanetary mission.

To accomplish such a mission with the chemical rocket, using higher energy propellants that we know today, it will take approximately 30 tons weight of a six-stage chemical rocket to accomplish the mission. This would require approximately 40 million pounds thrust to take off such a missile.

It is a very large device.

The CHAIRMAN. You say 40 million pounds?

Mr. DIXON. Forty million pounds of thrust. If you should accomplish this with the nuclear rocket, the studies show that you can do so with a two-stage nuclear rocket, and the total weight of the device is around 3 million pounds. That would mean of the takeoff thrust, approximately 4 million pounds thrust. This would also require a two-stage device.

As you can see, for a very ambitious mission, there is almost a tenfold advantage for the nuclear rocket over the chemical, in terms of size and weight and thrust of the device.

Let us look at another possible mission. This one here is a very similar mission in terms of a Mars orbit and return. In this case we would use a chemical rocket for the booster and the intermediate stages. For the final stage we would use a nuclear rocket, which would contain, of course, the payload.

In this case our comparison has shown if we use the nuclear rocket in the final upper stage, it would have a threefold advantage in the allowable payload over the chemical rocket. That means that in this mission comparison it provides about three times the payload that you can accomplish with the chemical rocket.

Let us now discuss some of the problems of the development of a nuclear rocket. The reactor is the major important factor of energy release of such a device. The temperatures, the liquid comes in cold and it must leave at a very high gas temperature in a gas state. The materials that are involved to handle these high temperatures must be selected to withstand these high temperatures. We will have such problems as erosion of the gases over the reactor, or corrosion.

In addition, the reactor must hold up at the high temperatures and high structure loads for the flow of these gases. In addition, the reactor must have controls. In this case you have a rocket sitting

on the ground and you want to start it. You must immediately release from the reactor the energy, and let the liquid flow through it very rapidly so that you can build up the thrust for the missile so you can take off very quickly.

This presents a development area on the controls of the reactor whereby you want to have the reactor cold and then in a matter of a few seconds, have it hot.

With respect to the engine systems, you must consider the materials of the other components of the rocket. There will be gamma radiation and neutron radiation from the reactor. Certain materials of an organic type will not withstand these radiations very long. You must select materials for your valves and your pumps that will withstand some radiation.

Of course, you must have certain areas shielded. Another problem, as you operate the rocket, there is some fissionable material that is exhausted from the gases. This is a function of the amount of erosion you have in your reactor. It is also a function of the length of time that you run the rocket, as well as the energy at which you operate the system, what temperature of the gases.

So you have to consider in your facilities which test the rocket the contamination of the gases. You will also have to protect your equipment. The development of the necessary turbopumps and tanks is another development area. We are fortunate in this country, due to the liquid rocket progress, that it is possible to make great strides in the development of this turbo machinery.

Engine controls is another development area. We want this device to flow to the reactor propellants at a very precise rate. You also want the device to flow the propellants to the reactor very quickly when you build up thrust, and at the cutoff of the engine, it must shut off at the proper time. So this requires precision engine controls.

I would like to mention other types of systems. We have discussed here a straightforward fission process of a reactor, a heat transfer from a solid state to a liquid, and then a standard pressure expansion cycle. There are other concepts for energy release such as you well know, the fission process and certain types of radio isotope decay types for energy. There are certain other methods of heat transfer to the fluids. Such ones I will mention as a solid to a fluid, and in this case this device is very similar to a centrifuge in separation of the solid. Another concept, if you have the fusion process, a large amount of energy is transferred to a gas. Then at the high temperatures the gases are ionized, and it is possible to accelerate these gases at high velocities by electromagnetic means. These types of devices are in the early research phases, and we will know more about those in the next few years.

In summary, the nuclear rocket offers a large payload. It offers vehicle simplification for very ambitious missions which would result in fewer stages and of course lower weight. A superior application will be where you have large payloads for satellites, space and planetary traffic.

Under the project Rover, the aims are to develop a nuclear rocket. We at Rocketdyne are an industry member of the team that is working with the Los Alamos laboratories, and we are working on the development of various components of the nuclear rocket. We believe, in conclusion, that a nuclear rocket is feasible and will be developed.

(The prepared statement of Mr. Dixon is as follows:)

Gentlemen, in accordance with the committee's request we have prepared a short statement, with accompanying charts, describing the characteristics and application of the nuclear rocket engine.

The energy limit of liquid propellant chemical rockets is in the neighborhood of 450 seconds of specific impulse or pounds of thrust developed by a pound of propellant in a given unit of time. As discussed in our earlier presentation on chemical rockets, performance much in excess of this is desirable for interplanetary flight.

Since the advent of controlled nuclear fission, propulsion engineers have considered the application of nuclear energy to propulsion devices. The nearly limitless energy offered by nuclear processes has tremendous appeal, but the effective utilization of this energy to produce useful thrust poses some difficult problems.

The most straight-forward method (Chart 1) appears to be the release of energy within a very high temperature reactor and the transfer of this energy to a suitable working fluid, or propellant, which is then expanded through a rocket nozzle.

CHART 1

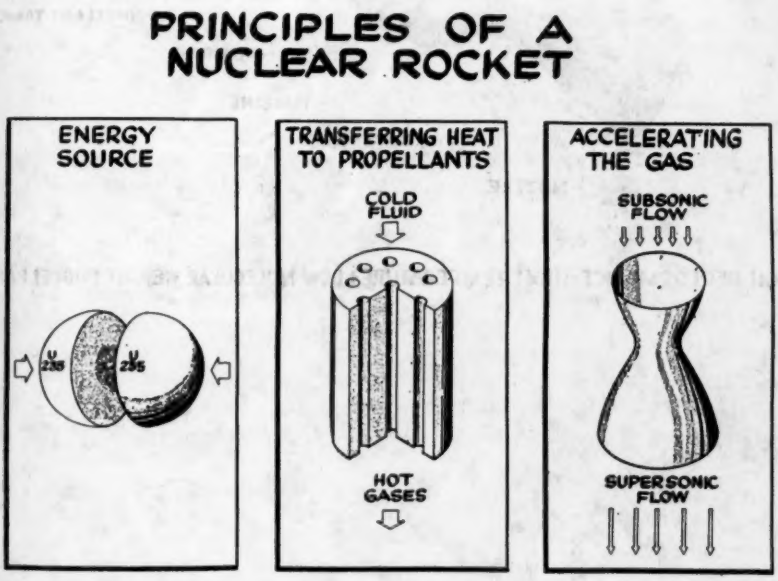


Chart (2) presents a concept of such a nuclear rocket engine. In essence, it differs from its chemical counterpart only in the replacement of the chemical combustion process by a nuclear heat source. The liquid propellant contained in the supply tank is pumped at high pressure into the reactor where it is superheated to very high temperatures, of the order of 4,000° to 5,000° F. After flowing out of the reactor, these hot, high-pressure gases are expanded through the nozzle to produce a high-velocity jet and a reaction thrust.

The performance of any rocket propellant system is dependent primarily upon the temperature of the gases and their molecular weight. In general, high performance can be obtained by either high gas temperatures and/or low molecular weight exhaust gases. In the case of the nuclear rocket engine we are describing, gas temperature is limited by the materials of which the reactor is constructed, but the designer has a somewhat wider latitude in his choice of propellant to achieve low molecular weight gases. From this standpoint, hydrogen would be the logical choice as a working fluid.

A typical nuclear rocket space vehicle is shown in chart (3).

CHART 2

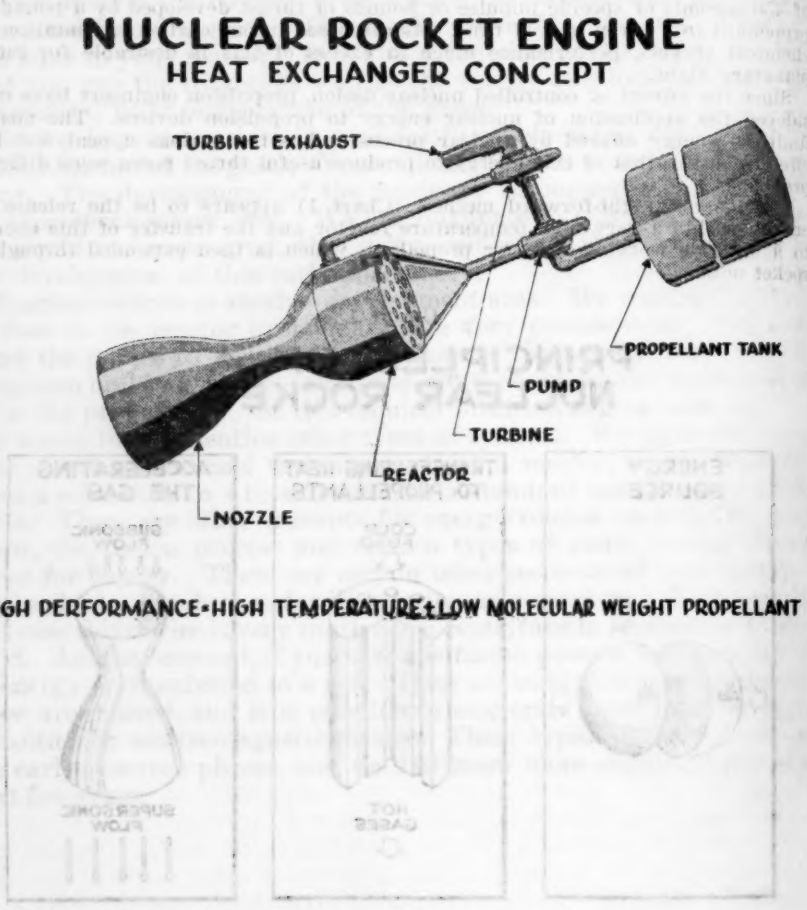
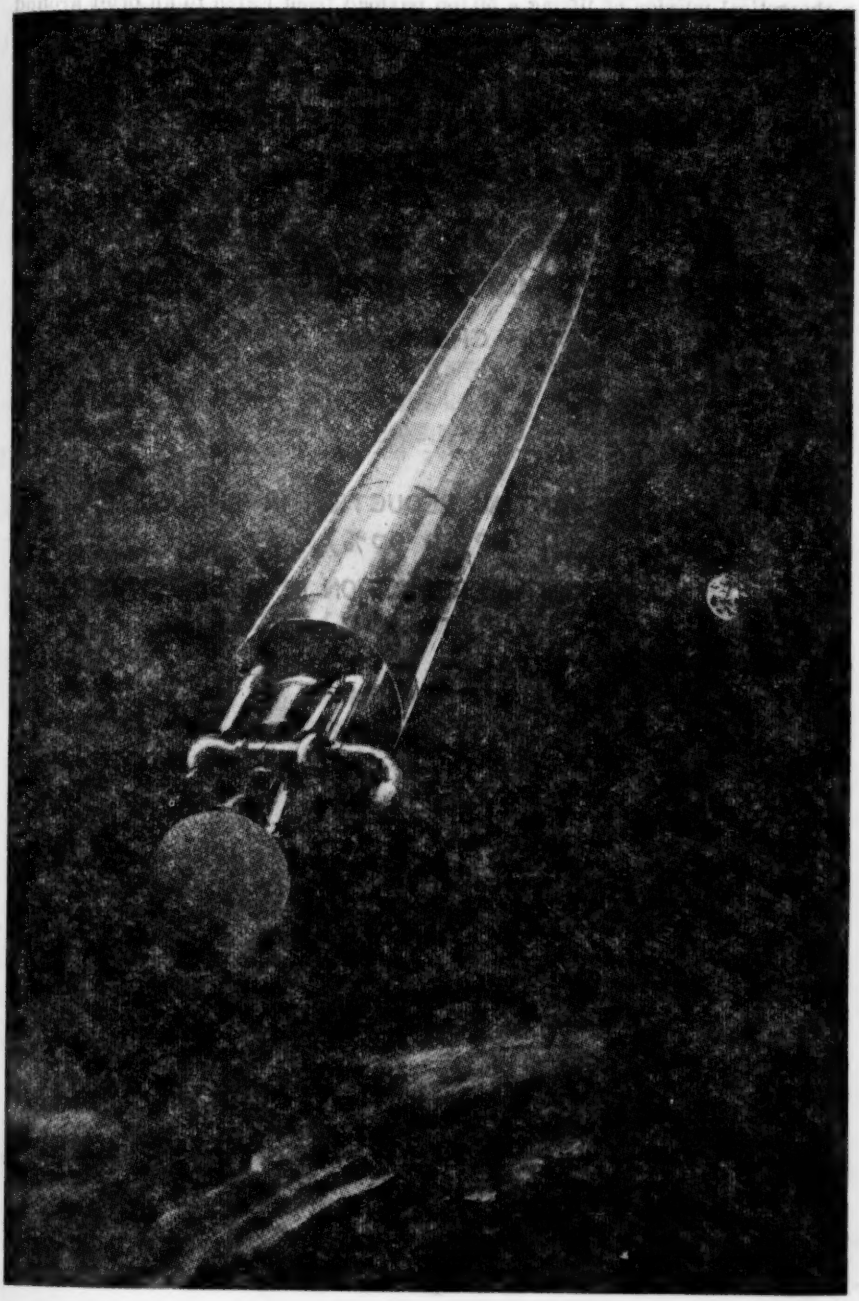


CHART 3

TYPICAL NUCLEAR ROCKET



To summarize interest in the nuclear rocket engine, I would like to turn to chart (4). The nuclear rocket engine offers performance up to 300 percent of that of the chemical rocket. This higher performance translates into a reduction of missile gross weight and takeoff thrust ranging up to 90 percent, depending upon the specific mission.

To compare nuclear and chemical powered rocket vehicles, we have selected a theoretical mission of lifting a 50-ton payload from Earth to an orbit around Mars and then returning to an orbit around Earth.

CHART 4

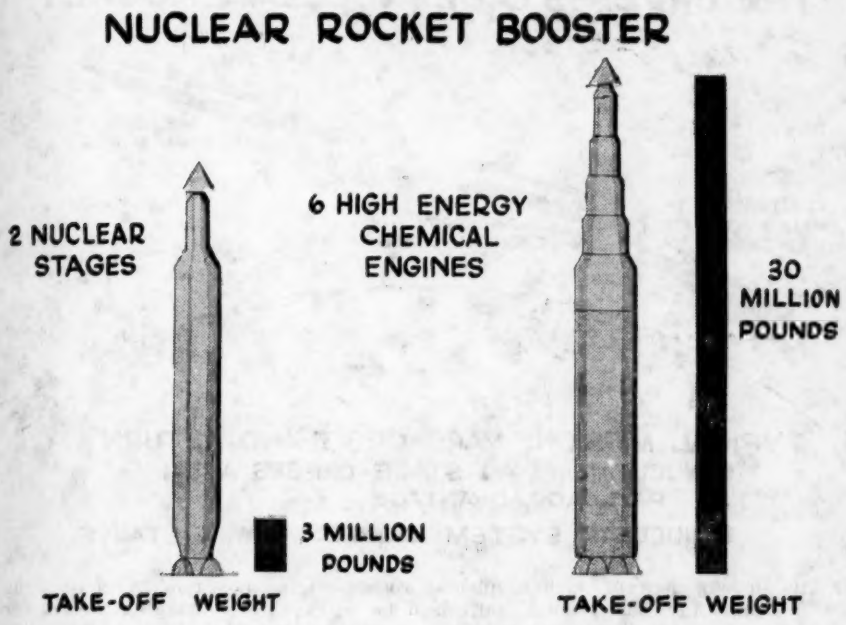
NUCLEAR ROCKET ENGINE CHARACTERISTICS

- HIGH PERFORMANCE (SPECIFIC IMPULSE)
  300% OF CHEMICAL
- RESULTS IN–
  SUBSTANTIAL REDUCTION IN THRUST (UP TO 90%)
  SUBSTANTIAL REDUCTION IN MISSILE WEIGHT (UP TO 90%)

Chart (5) presents the relative sizes and the takeoff weights of such vehicles. In this study, the performance level of the two-staged nuclear-powered vehicle is assumed to be approximately twice that of the six-staged high-energy chemical system. Comparison of the approximate vehicle takeoff weights indicates a tenfold weight advantage for the nuclear vehicle which translates into a tenfold advantage in the engine thrust requirements to accomplish this mission.

In addition, the fewer number of stages required by the nuclear-powered vehicle means less vehicle complexity, an important factor in overall reliability. The development of such large boosters will include work on reactors of extremely high power, the selection and construction of suitable test sites, the construction of propellant production plants, and safeguards against contamination and radiation.

CHART 5



Another interesting vehicle comparison is presented in chart (6). The goal here would be the acceleration of a fairly heavy vehicle from a low orbit around Earth to an orbit around Mars and then a return to the Earth orbit. The booster vehicle would be a cluster of million-pound thrust engines. A high-energy chemical second stage would place the third stage of Mars vehicle in its first Earth orbit.

By using a nuclear rocket engine of moderate power for the Mars vehicle, approximately 200 percent more payload could be carried on the trip than could be carried by a two-staged, high-energy chemical system of equivalent weight.

(Chart No. 6 referred to is as follows:)

CHART 6

THE UPPER-STAGE NUCLEAR ROCKET

TYPICAL MISSION: MARS ORBIT AND RETURN

- NUCLEAR FINAL STAGE OFFERS A 3:1 PAYLOAD ADVANTAGE
- NUCLEAR SYSTEM REQUIRES FEWER STAGES

The development of such a nuclear rocket engine poses many challenging tasks (chart 7). The reactor controls must be capable of bringing the reactor safely up to operating power within a matter of seconds. Reactor materials will be required to operate at very high temperatures without erosion, corrosion, or change in physical characteristics. The fabrication of reactor parts will require new production techniques. In addition, materials for components of the rest of the engine system must be selected with possible heat and radiation effects in mind.

(Chart 7 follows.)

CHART 7

NUCLEAR ROCKET DEVELOPMENT PROBLEMS

REACTOR

- CONTROLS
- MATERIALS

ENGINE SYSTEMS

- MATERIALS
- RADIATION EFFECTS
- RADIATION SHIELDING
- CONTAMINATION
- PROPELLANT TURBOPUMP & TANKS
- ENGINE CONTROLS

Methods must be provided to reduce heat from neutron and gamma radiation in adjacent engine components and propellant tanks. Also, adjacent structural elements must be protected from induced radioactivity. During the early development stage, heavy radiation shielding will probably be employed to protect critical areas of the engine system and its test stand structure.

In flight, however, heavy shielding would severely penalize potential payloads and can be employed only sparingly and only in the most critical areas. As an alternate, it is possible that the reactor thrust chamber assembly will be separated from the rest of the propulsion system, thus trading distance for shielding weight.

The fission fragments produced by the nuclear processes within the reactor create yet another consideration. If these products were allowed to migrate out of the reactor and were carried by the propellant into the exhaust jet, contamination of the test stand and nearby areas could occur.

The extent of the contamination would depend on the quantity of fission products that escape, the power level, and the length of time that the reactor operates. For reactors of moderate power, the burnup of fissionable material should be quite small, so that contamination should not be particularly troublesome.

Work on suitable turbopumps and propellant tanks is already underway in state-of-the-art development programs. It is sufficient to say that required components of this type can be provided by the time useful reactors will be available.

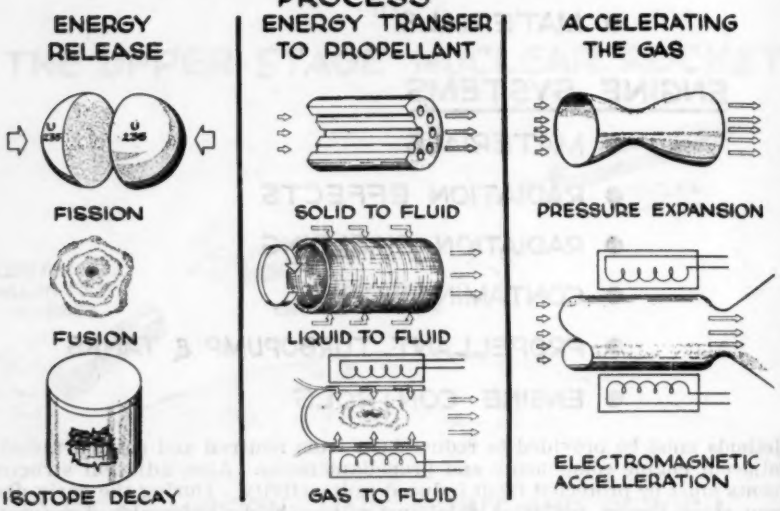
The systems which we have just discussed all utilize the heat-exchanger-type of nuclear rocket. However, there are other concepts for applying nuclear energy to rocket propulsion. Chart (8) shows other possible concepts for the release of energy, energy transfer, and acceleration of the working fluid to high exhaust velocities.

Energy released by nuclear fusion or the decay of radioactive isotopes, energy transfer by liquid to fluid or gas to fluid devices, and acceleration of the working fluid to high velocity by electromagnetic fields are shown. On the basis of

current state of the art, the fission reactor-solid heat exchanger with the pressure expansion nozzle is the most logical choice for early development. Most of the other concepts for applying unclear energy to propulsion are in the early research phases and may have potential at some future time.

CHART 8

APPLYING NUCLEAR ENERGY TO ROCKET PROPULSION



Nuclear rocket propulsion will occupy an important role in the conquest of space (Chart 9). Because of the high performance potential of nuclear rockets, space vehicles employing such propulsion systems can deliver larger payloads with fewer stages. This capability opens the door to the establishment of larger satellites and planetary bases for future space exploration.

CHART 9

SUMMARY

NUCLEAR ROCKETS OFFER:

- LARGER PAYLOADS
- VEHICLE SIMPLIFICATION
  - FEWER STAGES
  - LOWER WEIGHT
- SUPERIOR APPLICATIONS FOR:
  - LARGE SATELLITES
  - PLANETARY BASES
  - SPACE EXPLORATION

NUCLEAR ROCKETS ARE FEASIBLE AND WILL BE DEVELOPED

The Nation's nuclear rocket program, Project Rover, aims to develop a nuclear engine. The industry team, of which Rocketdyne is a part, is working with the Los Alamos Laboratory on the various problems.

It is believed that the nuclear rocket is feasible and will be developed for future space applications.

The CHAIRMAN. Mr. Dixon, we have followed your charts very closely. You don't have any idea, do you, at this time that the nuclear rockets will take over the chemical rockets at any later date?

Mr. DIXON. Mr. Chairman, I believe we are in a phase now that the chemical rocket will be used for many years. I believe someday we want to have these ambitious missions for space flight, and the nuclear rocket will come into play to accomplish these types of programs.

The CHAIRMAN. You envision the idea that we will need chemical and nuclear rockets? Each have an adaptation?

Mr. DIXON. That is right. Each will have a place in some of our future missions, and in the next 10 years I am sure the chemical rocket will play the most important part.

The CHAIRMAN. How far off is the nuclear rocket?

Mr. DIXON. We believe the nuclear rocket can be developed between 5 and 10 years.

The CHAIRMAN. Without going into any matter you shouldn't discuss here in the open meeting, what is the chief reason for the holdup in the development of the nuclear rocket?

Mr. DIXON. I don't know of any hold up. Essentially we are in the early research phase for the Government agencies, the aim being to develop a nuclear rocket and we are proceeding accordingly. We at Rocketdyne are part of the industry team that is working with the Government laboratories in this program.

The CHAIRMAN. I understand that now. But what is your problem? Is it the development of the proper materials or is it that the theoretical formula has not yet been worked out, or just what seems to be the whole problem as of this hour?

Mr. DIXON. The major problem of this is the development of this energy device here. This involves the development of suitable materials that will hold up at these high temperatures against the erosion and corrosion problems.

The CHAIRMAN. The creation of the heat and the transferring of the heat to liquids, which in turn will be the propellants: That is your problem, then?

Mr. DIXON. Yes; that is the major problem.

The CHAIRMAN. Of course that is the engine. So your hold-up then is in the development of a suitable engine.

Mr. DIXON. I think that is essentially a standard research and development problem that each particular problem must be solved logically in the steps that you proceed through in any development of an engine.

The CHAIRMAN. Are you pushing your program as fast as you would like to have it pushed out there?

Mr. DIXON. We can see certain areas where more development can be accomplished faster. We visualize that by additional effort some of the problems could be solved faster.

The CHAIRMAN. When you say "additional effort," you really mean additional money?

Mr. DIXON. Which would involve additional funds.

The CHAIRMAN. Can you get the engineers and the chemists and the scientists that you need?

Mr. DIXON. Yes, sir, we have those available.

The CHAIRMAN. There is no shortage at all?

Mr. DIXON. No, sir. This being such an interesting program, we have no difficulty. Most of the engineers at Rocketdyne would like to work on this type of effort.

The CHAIRMAN. They are good scientists and good engineers?

Mr. DIXON. Yes. Of course, our Los Alamos laboratories are the greatest in the world. For the engineering support, we have very capable teams that can accomplish the development of some of the engine components of the system such as the turbo machinery, the valves and controls. We have a very able team in that field.

The CHAIRMAN. You don't know of any scientists or engineers anywhere else in the world better than the ones we have here, do you?

Mr. DIXON. I don't know of any.

The CHAIRMAN. Any questions?

Mr. Miller.

Mr. MILLER. I notice you say that this is for a very ambitious mission. Could you conceive a nuclear power plant being put into, say an intermediate range ballistic missile?

Mr. DIXON. No, sir, I don't conceive that the nuclear rocket will be used for military missions.

Mr. MILLER. Not for military missions.

Mr. DIXON. No, sir.

Mr. MILLER. What would be the effect if we had one of these things and it got up and something went wrong and it returned to earth—only got up a few miles and had to come down? Would we scatter hot uranium all over the countryside?

Mr. DIXON. This certainly would have to be considered, since this contains fissionable materials, if it did come down on the earth's surface, it would scatter certain fissionable materials, and we would have to decontaminate that area.

Mr. MILLER. Of course, it could be in a container stout enough——

Mr. DIXON. Yes; that is true.

Mr. MILLER. There is no danger of it exploding. It wouldn't be an atomic bomb. It would just be the physical breakout of the container that would allow the fissionable material to be scattered.

Mr. DIXON. The worst that could happen is this could melt down. That is essentially about the limit of what would happen.

But in some of our chemical rockets that have landed on the surface, we have found we can recover some of the major portions of the engine. In some cases we have recovered the whole engine and cleaned it up and fired it in flight again.

So it is possible in landing that the whole device may hold together.

The CHAIRMAN. Mr. Bass.

Mr. BASS. Looking at your chart there at the intermediate or center picture, what fluid do you contemplate being changed from a fluid into a gas?

Mr. DIXON. The fluid such as liquid hydrogen, in the liquid state. It is very light weight and will flow through your reactor, the heating from the fissionable reaction, and then go from a liquid state to a vapor state, and then continue to heat due to the fact of the heat source there.

The CHAIRMAN. Mr. Daddario.

Mr. DADDARIO. Mr. Dixon, will you explain to us just what Project Rover is?

Mr. DIXON. Project Rover is a project that has been set up by the Government agencies to look into the development of a nuclear rocket.

Mr. DADDARIO. When was Project Rover initiated, and by whom?

Mr. DIXON. My memory may be rusty in this area, but I believe it was around approximately 3 years ago—1955—that the Rover program was initiated by the Atomic Energy Commission and is a team effort of the U.S. Air Force and industry.

Mr. DADDARIO. Then we do have in this particular instance, when we talk about Project Rover, an effort to develop a propellent engine through the Atomic Energy Commission, rather than through NASA or the ballistic missiles agencies or anything of that type.

Mr. DIXON. The NASA organization, with the Atomic Energy Commission and industry, I am sure, are all participating in this program.

Mr. DADDARIO. Is there a definite tieup between these two that you know of? You say "probably are." Are you sure they are?

Mr. DIXON. I am sure there is a tie up.

Mr. DADDARIO. Can you tell me how much the Government has set aside for Project Rover in dollar amounts for the development of a nuclear rocket?

Mr. DIXON. I am not sure of the exact dollars, but it has been published in various articles, and they said in 1958 there was around $20 million allocated for Project Rover.

Mr. DADDARIO. $20 million in the 1958 budget for——

Mr. DIXON. Project Rover.

Mr. DADDARIO. Is that the full amount of money that you know of that is being expended for nuclear development?

Mr. DIXON. I am not sure.

Mr. DADDARIO. Do you feel that what you know of Project Rover, with the $20 million involved—taking into consideration the effort involved here—that that is a sufficient sum of money to develop this kind of a vehicle?

Mr. DIXON. I believe more effort could be placed on this program. Probably about twice the level of effort that is placed on it now undoubtedly would speed up the whole program.

Mr. DADDARIO. When you take into consideration, sir, that in your chart you show the great savings would be in size and in possibilities of what these vehicles could then do, once developed, wouldn't you think that this extra effort should be made?

As I understand it, you would say if you had $40 million you could do just about what you wanted to do in this field? You said we could make twice the effort.

Mr. DIXON. Your question?

Mr. DADDARIO. My question is, going back to what you have just said, you don't mean a tenfold effort, but perhaps just doubling the effort, which means that if $20 million is now being spent on Project Rover, that $40 million would allow you to do the kind of a job that you feel should be done in this particular area at this time.

Mr. DIXON. Yes, I believe it would certainly result in a more effective program that could make more progress than you are doing today.

Mr. DADDARIO. Do you feel that you have the capacity, both in plants and scientists and know-how to efficiently expend this extra money if it were to be allotted to you?

Mr. DIXON. With respect to our company's participation as a team effort, mainly in the other components of the rocket engine, we have the sufficient manpower and capabilities to accomplish that portion of the program.

Mr. DADDARIO. And to expand?

Mr. DIXON. And to expand; yes, sir.

Mr. DADDARIO. Do you feel this should be done? Do you feel this expansion should take place? If so, should it take place immediately, or is there a lag in time?

Mr. DIXON. I feel that your future requirements over the next 5 to 10 years will require us to have large payloads in space. By proceeding now with additional effort we can make progress to the point that we will know what the characteristics of this device are, know how to use it in an early program.

Mr. DADDARIO. You would recommend, then, if an extra $20 million could be made available for nuclear development, that it should be done now, that you have the capacity to do it, and that it would certainly put us to the point where 5 years from now we would have this portion of the research and development behind us?

Mr. DIXON. Yes, sir.

Mr. BASS. Would you yield on that?

The CHAIRMAN. Mr. Bass.

Mr. BASS. Just for the record, as I understood you, Mr. Dixon, your setup in Rocketdyne is proceeding satisfactorily in your opinion?

Mr. DIXON. Yes; it is proceeding satisfactorily.

Mr. BASS. You are making your maximum effort in this field?

Mr. DIXON. No; we are not making our maximum effort. We are proceeding satisfactorily. We could go faster.

Mr. BASS. If it is satisfactory, it must be maximum.

Mr. DIXON. Satisfactory would mean that what we are doing and accomplishing, with what funds we have, and meeting our objectives—What I mean is, we could meet these objectives earlier if more funds were provided.

Mr. BASS. With more funding, that means hiring more scientists, engineers, and personnel to increase your effort, does it not?

Mr. DIXON. I would like to point out, as Mr. Hoffman did in the early part of the sessions, the ballistic-missile rocket-engines programs—Atlas, Thor, and Jupiter—major development phase has been accomplished. We are now in the production phase of such devices. We have in our organization these same development engineers that are becoming available, whereby some of them could work on this particular program. We would not have to hire new people. These talents are available now to work on the phases that we would participate in on this program.

Mr. BASS. What are these people doing now?

Mr. DIXON. They are in the phase of cleaning up, on developments and what we call final qualification type testing.

If we don't let them work on such programs as these, they will be back into the other industries.

Mr. DADDARIO. Just to finish up, as I understand it, then, Mr. Dixon, when you say you are doing a satisfactory job at this time, you mean

that with what you have available, you are making the maximum effort.

If you had more available, you could do much more and accomplish a great deal to get the kind of an engine that you have described here this morning, at an earlier date?

Mr. DIXON. Yes, sir.

The CHAIRMAN. Any further questions?

Let me ask Dr. Gunn this, if I may. He is Project Rover manager at your company. All of this is research and development, isn't that right?

Dr. GUNN. Yes, sir, the effort that is going on at Rocketdyne now is mainly development of certain components that could be used in such a system.

The CHAIRMAN. What I want to ask is this: I have been asking all of the companies to give us some idea of their research and development program. Did you give that yesterday, Doctor?

Dr. DUNN. No, sir; I was not here yesterday.

The CHAIRMAN. What is the size of your research and development program?

Dr. GUNN. Fundwise or manpower?

The CHAIRMAN. Both ways.

Dr. GUNN. We are running at about $1.9 million a year right now, associated mainly with the development of a suitable pump. Our manpower level is something around 60-odd people.

The CHAIRMAN. Sixty-odd people?

Dr. GUNN. Sixty-odd—63 or 64.

The CHAIRMAN. They all are working on one pump?

Dr. GUNN. Yes, with the development of the pump and its associated problems.

The CHAIRMAN. So they are the scientists and the engineers that we have referred to, is that right?

Dr. GUNN. That is correct, sir.

The CHAIRMAN. When they complete the development of that pump, they would be available for a project such as this?

Dr. GUNN. In addition to the people we have on the pump, we have other team members who are in the company.

The CHAIRMAN. Aren't they in research and development?

Dr. GUNN. They are in research and in systems study work. We also have people available to start on the turbine, which is all design.

The CHAIRMAN. Is systems study work, research and development?

Dr. GUNN. Yes, I would classify it as that.

The CHAIRMAN. Have you included that in the $1.9 million?

Dr. GUNN. The $1.9 million is the funding set aside this year, the current phase of our program, for the development of the pump. There are 60-some-odd people involved in that effort. Over and above these people, there are additional people who are standing by, awaiting the opportunity to get on with some of the other phases of the program. These people are engaged in certain studies and applications of such propulsion systems.

The CHAIRMAN. Then as I understand it, your total R. & D. program is $1.9 million, a little less than $2 million.

Dr. GUNN. That is correct, sir.

The CHAIRMAN. I think that covers it.

Mr. Moeller.

Mr. MOELLER. Mr. Chairman, may I ask Mr. Dixon a number of questions. You presented a very intelligible study. However, I fail to observe enthusiasm on your part for this thing. Are you fearful of it? Is there something about this nuclear rocket that you didn't tell us, that it may not be what we are hoping it would be?

Mr. DIXON. No. I think the nuclear rocket is the next step for large energies available after the chemical rocket. I hope I haven't shown a lack of enthusiasm. I think this is the next area of propulsion we will have for space for both upper stages as well as for boosters in the future.

Mr. MOELLER. You don't feel it is far enough along, then, that you could immediately sell the idea? You feel that the chemicals must precede it yet for a while, simply for feasibility, for practicality?

Mr. DIXON. Yes, sir. I believe that we should proceed with the development of this device as fast as we can, and certainly there will be many applications I think in the next 5 to 10 years. You will have many applications where you want small payloads in orbits, or you want to have small payloads for interplanetary missions.

The chemical rocket will accomplish this. Then there will be a time that you will want to place large payloads in space. The nuclear rocket will be your answer for that.

Mr. MOELLER. What information can you gather from the engine device in our submarines for example, that would be helpful in a rocket? Can you use any of this at all? Or are the systems so entirely different from one another?

Mr. DIXON. No, I don't think so. It is a different level of power that is required. For the nuclear rocket, it is a very high-level power reactor. I think the submarine has a very low-power level.

Mr. MOELLER. May I ask: Do you happen to know what Russia might be doing in this field?

Mr. DIXON. No, sir, I don't know what they are doing.

Mr. MOELLER. Would you be able to say about when these might appear? Did you say 10 years?

Mr. DIXON. Five to ten years.

Mr. MOELLER. And will be considerably cheaper than the chemical type.

Mr. DIXON. I don't think it is going to be cheaper. We are going to have fissionable materials in the reactor. These are expensive.

The CHAIRMAN. I want to thank you gentlemen very much for coming here and giving us the benefit——

Mr. KARTH. Mr. Chairman, could I ask a question?

The CHAIRMAN. Surely, Mr. Karth.

Mr. KARTH. Has it been decided yet whether or not nuclear propulsion is a feasible method of propulsion?

Dr. GUNN. Maybe I could try to answer your question. As you probably know, there are preparations now underway in Nevada for the conduct of what is known as the Kiwi–A reactor experiment. To answer your question, you have to define what you mean by feasible.

Mr. KARTH. There has been some doubt expressed in the last couple of days as to whether or not a nuclear propulsion would even be a feasible method of propulsion. Just yesterday or the day before, upon my question, it was testified by one of the people who appeared before the committee that it would take about $50 million of basic research to decide whether or not nuclear propulsion would be feasible.

My question is: Have you people—has your company, decided whether or not nuclear propulsion is feasible at this stage, after expending a small portion of that money?

Dr. GUNN. On the basis of the information that we have, we have concluded that it is feasible. This opinion may be temporarily changed as a result of the outcome of the test in Nevada, but we know of no obstacles that we have run into, or are aware of, that state it is not feasible at this time.

Mr. KARTH. Have you decided whether or not nuclear propulsion would be feasible in the first stage of a rocket, for example? Or do you feel after your experimentation that it would be impractical as a first stage of propulsion?

Dr. GUNN. I think the suitability of nuclear rockets for the types of missions you were describing—that is, upper stage versus big boosters—is a question of timing. And that in the early phases of the program it is easier to do the job, get around, circumvent, some of the other problems such as the production of large quantities of propellant and preparation of suitable test sites by shooting for something less ambitious, in the way of a thrust level, and hence this means that such a system will probably find utilization first as an upper-stage device.

However, there still is nothing we know of yet today that we can say firmly precludes the use of a nuclear rocket in a large booster application.

The CHAIRMAN. Any further questions?

Mr. Wolf.

Mr. WOLF. Mr. Chairman, might I ask one question of anyone in the room. Is there any research—and if there is, has it been demonstrated of any help to us—on a cheaper source of a fissionable material than uranium? Is any research being done anywhere in the United States to find a cheaper source for fissionable material?

Dr. GUNN. I think really the cost that we are alluding to here, or suggesting, is not so much the cost of the raw material itself, but rather in handling the device and engineering it and making it work as a system, the test site problems, the radioactivity and contamination problems. These are pretty much common, regardless of what the fission source is.

The CHAIRMAN. I think we had better proceed. We have two more groups of witnesses here this morning.

We want to thank you gentlemen very much for coming here and helping us. We value your testimony very highly.

Now we will call Dr. Arthur Biehl, vice president and technical director of the Aerojet-General Nucleonics Division from California.

Dr. Biehl.

STATEMENT OF DR. ARTHUR BIEHL, VICE PRESIDENT AND TECHNICAL DIRECTOR, AEROJET-GENERAL NUCLEONICS DIVISION

Dr. BIEHL. Mr. Chairman, I have a prepared statement here. I would like to read it if that is satisfactory.

The CHAIRMAN. Fine.

Dr. BIEHL. The title of it is "The Role of Atomic Energy in Space in the Next Decade," and I have included some matter besides just propulsion, if that is admissible.

With the advent of increased interest in space exploration, the question has arisen as to the role of nuclear systems in space within the next decade. I will try and limit my discussion just to this next decade.

In considering this question, it is, of course, necessary to consider the advantages and disadvantages of a nuclear system as compared to a chemical system for certain missions, the potential value of such missions, and where the nuclear system appears to be advantageous. One must also consider both the technical feasibility and the most desirable type of nuclear system.

In this regard, for certain missions, nuclear systems clearly appear to have certain advantages over chemical systems when used as a propulsive means or as a way of supplying auxiliary power.

The advantages of the use of nuclear energy in space applications primarily stem from the fact that there is potentially available some 100 million times more energy per unit weight from nuclear fuels than there is from the best chemical fuels. However, this advantage cannot always be fully realized and is accompanied by the disadvantages of the presence of nuclear radiations, as well as the limitation of a minimum size (and weight) in which a nuclear reactor package can be built.

In certain applications the effects of radiation do not constitute too serious a disadvantage although in other, particularly manned applications, the necessity for shielding from the radiation can be a serious penalty.

Similarly, the minimum size for the generation of energy by means of a nuclear reactor system may not be a serious penalty, particularly in those systems operating at high power such as is required for nuclear rockets of the Rover type—I think that will be discussed tomorrow in some detail—for electrical propulsion systems, et cetera.

However, for many applications, the use of nuclear energy, when compared to the use of chemical energy for a given mission, is seriously hampered by the inability, with present technology, to build very small, light, nuclear reactors. One of the few exceptions is the utilization of radioactive isotopes for auxiliary power systems in space, as has been recently discussed on the chart.

Before considering in some detail what type of nuclear systems can be used in space, it is probably worthwhile to review the types and characteristics of some of the missions in which the nuclear systems could be the least expensive, and the best way of obtaining successful performance.

1. POSSIBLE MISSIONS FOR NUCLEAR PROPULSION SYSTEMS

A round-trip mission to Mars appears to be one of the missions in which nuclear propulsion systems are potentially superior to chemical systems. Such a mission can be visualized as using chemical boosters to place a nuclear propulsive system in orbit around the earth.

The nuclear system would then take over and propel the rocket to Mars, orbit Mars, and then return the rocket to orbit about the earth where it could then re-enter the atmosphere and could be recovered. For such a mission it is worthwhile to compare quantitatively the incremental velocities required to perform such a mission by means of both a high thrust, as well as a low thrust system. By a "high thrust system" we mean the case where the thrust of the rocket is

approximately equal to the weight of the rocket, and in this regard, it is similar to the thrust weight ratio of most of the familiar chemical rockets used today.

By a "low thrust system" (such as ion propulsion systems)—I think that will be discussed tomorrow in some detail — we mean a system which has a thrust of 1/10,000 or less of the weight of the system. Interestingly enough, a high-thrust system is much more economical in the use of its fuel in performing the aforementioned Mars mission in that it only requires an incremental velocity of about 11 kilometers per second — this is about 36,000 feet per second in other units — whereas for a low-thrust system performing exactly the same mission, an incremental velocity of approximately 33 kilometers per second is required.

Thus, we see that if both high- and low-thrust systems could be obtained with the same effort, weights, et cetera, the high thrust system is always preferable in that it means a much smaller and lighter overall system, other things being equal.

In considering a rocket to perform the aforementioned mission, it is interesting to compare the potential performance of the nuclear rocket with that of a chemical rocket in terms of the exhaust velocities which may be expected to be obtained in these systems within the next decade.

Specifically, a chemical rocket, due to the nature of the chemical bond and to the chemical fuel used, is limited to an exhaust velocity of approximately 4 kilometers per second (12,500 foot-second), whereas nuclear systems have been proposed with exhaust velocities as high as 8 kilometers per second for a high-thrust system, (25,-000 foot-second), and as high as 100 kilometers per second (or even higher) for low thrust systems (such as ion propulsion systems decribed herein).

I might explain, 4 kilometers per second is equivalent to a specific impulse of about 400 seconds. Eight kilometers per second exhaust velocity is equivalent to a specific impulse of 800 seconds in other units.

Now, the higher the exhaust velocity that can be obtained, the less fuel it is necessary to carry along on a mission; accordingly, the smaller and lighter the overall system. For example, a chemical propulsion system having an exhaust velocity of 4 kilometers per second—that is 400 seconds of specific impulse—of a high-thrust type for the aforementioned Mars mission, would require a mass of fuel some 15 times the dry weight of the rocket system.

In comparison, a nuclear propulsive system having an exhaust velocity of 8 kilometers per second and again of a high-thrust nature, would require a mass of fuel only some four times the dry weight of the system. Thus, we can see that, for nearly similar dry weights, the nuclear rocket would be considerably smaller and lighter.

In fact, the low-thrust system only becomes of interest when one can envision exhaust velocities in a range of 30 to 100 kilometers per second. These have been proposed for ion propulsion systems. For these high-exhaust velocities the weight of fuel necessary is only some two or three times the dry weight.

A round trip involving a landing on the moon is another potential system for the use of nuclear propulsion. What has been said in regard to the aforementioned Mars mission is true to a lesser extent in the case of the moon mission, although the advantages of a nuclear

system over a chemical system cannot be argued nearly as strongly and, in fact, does not appear to offer sufficient advantage as to justify a concerted effort for this mission.

It will be specifically noted that nuclear rockets, specifically of the Rover type—that is, the high-thrust type—for use as booster rockets, have been omitted. We have reached the conclusion, after considerable study, that nuclear rockets for boosters may not be a good application of nuclear energy in space, although this subject is currently under considerable debate among technical people.

2. ROVER

We at Aerojet have the good fortune to have participated in the Rover project. The system consists of a high-temperature nuclear reactor using hydrogen as the propulsive gas. In such a system, the hydrogen is pumped through the reactor where it is heated by normal heat transfer, and then expanded through a nozzle to provide the rocket thrust.

By such a system, thrusts of slightly greater than 1 g and exhaust velocities of 8 kilometers per second may be obtained using current state of the art technique and special high temperature materials. The feasibility of such a system is unquestionable, the principal problems involved being the high-temperature materials used in the nuclear reactor, fabrication of high-pressure, high-capacity hydrogen pumps, et cetera; it is our opinion that, with sufficient financial support, such a system may readily be made available within the next 10 years and will prove to be a most useful post-booster propulsive system for missions requiring a high incremental velocity such as the Mars mission described above.

3. ELECTRICAL PROPULSIVE SYSTEMS

A rather great variety of electrical propulsive systems have been proposed within the last few years. Almost all of these systems, whether they go under the name of ion propulsion systems, colloid propulsion systems, magneto-hydrodynamic systems, or whatever it might be, have the common characteristics of providing low thrust (one ten-thousandth g) and all of the systems we have studied require considerable technical development, some of which might be called "breakthroughs" in order to achieve desired performance.

The principal technical problem that remains to be solved before such electrical propulsive systems may be considered to be practical, is the means for producing the high current of charged particles at the desired high velocity.

For example, typical systems require currents of as high as 500 to 1,000 amperes, at an acceleration voltage of typically 2,000 volts. The current state of the art lags behind this goal by a factor of a thousand or more, that is, the highest currents that have been obtained in the laboratory are some fractions of amperes.

Of course, Aerojet is working on a number of these systems, and we believe that in the next 10 years at least one, and probably more, satisfactory systems will be obtained in the laboratory. It very well could be a longer period before the first space mission would be launched using a most-boosted electrical propulsion system.

Another problem that exists in electrical propulsion systems, is the critical nature of the weight of the nuclear powerplant for gen-

erating the required energy. Again, Aerojet has been working on the problem, and although considerable development is required, no technical breakthrough or new scientific information is needed to satisfy the required powerplant weight.

4. HYDROGEN PROPULSION REACTOR

We at Aerojet have been working on a combination of the above-mentioned Rover and electrical propulsion systems providing an intermediate thrust. We visualize such a system as utilizing currently developed low-temperature gas cooled reactors, where the hydrogen after passing through the reactor core is expanded through a turbine which, in turn, drives a generator.

This process is repeated some 3 times and then finally the hydrogen on coming from the reactor is heated by means of the electrical energy generated in the aforementioned generators. Such a system appears to be doable in a considerably shorter time scale than Rover, and for considerably less money, since it uses already developed gas-cooled reactors. This system does not have the high temperature problems of Rover nor the ion gun problems of the electrical propulsion system.

We feel sure that such intermediate systems will be pursued in the next decade, particularly since they are also capable of supplying large blocks of electrical power for other applications in space.

5. SUPERSYSTEMS

A fairly large number of other applications of nuclear technology to space propulsion have been proposed during the last few years. Some of these are described in Bussard's book on nuclear rockets, and all have the common characteristic of requiring at least one technical breakthrough before they can be considered as practical systems.

Among the systems which have been proposed, are the intimate mixing of the fuel and gaseous uranium, and then the separation of the uranium from the fuel before expulsion from the rocket. Another is the use of nuclear detonations, that is, nuclear weapons, to provide large blocks of energy which literally blow the rocket out of the earth's atmosphere.

We at Aerojet have studied many, many of these systems and will continue to do so in the future. As to how soon one or more of these systems might be considered practical enough in order to warrant an experimental program and then a hardware development program, and finally see an application in space exploration, time can only tell.

Breakthroughs are occurring every day, but in the next 10 years it is not likely for a breakthrough to occur in one of these superperformance systems which could allow any one of them to be operational in that time interval.

Another application of nuclear energy in space exploration is the use of nuclear energy to supply power for instruments, communications, environmental control, and housekeeping loads, as well as a primary power source for the aforementioned electrical propulsive systems. We at Aerojet have again been conducting systems studies, as well as some detailed design of nuclear reactors for most of the above-mentioned uses.

We feel sure that the only practical way of supplying large blocks of power for space applications for longtime durations, is by means of nuclear technology. In this regard, although there are many problem

areas requiring engineering development, there does not appear to be any fundamental reason why the United States cannot have powerplants in space at reasonable weights within the next 10 years.

Such plants having weights as low as 10,000 pounds can supply as much as 1 megawatt of electrical power for time periods of 1 year or even longer—this is the typical power required for an electrical propulsion system, which you will hear about tomorrow—or, plants having weights as low as 3,000 pounds, including shielding for manned vehicles, can supply 20 kilowatts of electrical power for similar time periods.

If we are going to have men in space, if we are going to have electrical propulsive systems, we must have these nuclear auxiliary power systems. Such systems, although costly for the engineering and development, could be made available in the time period under consideration.

In regard to such nuclear auxiliary power systems, we believe there is also an application if we are to have manned lunar stations. Again one of the primary problems in setting up a base on the moon is going to be the electrical power required for housekeeping and environmental purposes.

Accordingly, we believe that these plants should be under design and development at the present time if we plan such habitation of the moon. We believe it is not impossible that such plants could be built and moved there with chemical rocket systems within the next decade.

An interesting thought on an application of nuclear energy to space is the possibility of setting up a nuclear power generation station on Mars, whereby the station power would be used for decomposing water into the chemical fuels, hydrogen and oxygen, for use in chemical propulsive rockets. Indeed, we are studying this problem at Aerojet and find that for a manned mission to Mars, such a system offers considerable advantage over performing the mission by means of a Rover nuclear rocket. Again, we believe that starting today, it is not impossible that such a system could be developed, and made operational within the next 10 years.

In conclusion I would like to summarize my thoughts as follows:

1. The applications of nuclear energy to the exploration of space are many, but they must always be considered economically with other systems such as chemical systems for the missions. Nuclear systems are not always the best.

2. Project Rover is worthwhile for many space applications and should be pursued for these applications.

3. Electrical propulsion systems are a long way off—that is, compared to 10 years—and, although the ultimate for long missions, are not a cure-all.

4. Nuclear auxiliary power units are a must.

The CHAIRMAN. That last statement impressed me most of all when you say nuclear power units are a must.

Dr. BIEHL. Yes, sir.

The CHAIRMAN. If that is true, we certainly ought to push them as rapidly as we can. Have you any suggestions, offhand, as to how they could be pushed?

Dr. BIEHL. I think the Atomic Energy Commission is already active in this field. Continuing on, though, I do not know of any, let me say, hardware work going on for 1-megawatt plants for space or any high-powerplants and I think this will certainly be needed in the future

if we are going to have ion propulsive systems or we are going to have people on the moon or men in space for a long duration.

The CHAIRMAN. We should be developing a megawatt powerplant of electricity?

Dr. BIEHL. I would like to think of at least two types we should be developing in a range of from say 10 to 100 kilowatts for space applications and a range of 1 to 10 megawatts for ion propulsive systems.

The CHAIRMAN. I was intrigued by something you said earlier in your statement, that certainly for the time being you feel that chemical powerplants are preferable in manned satellites.

Dr. BIEHL. No, I didn't say that. In fact, the weights are excessive to use a chemical power plant for longtime duration at high power in space. You just can't carry a long enough fuel.

The CHAIRMAN. So they are not preferred for manned vehicles?

Dr. BIEHL. You have to supply the shielding and use a nuclear powerplant. Let me describe typically, if you are going to have half a dozen men in space, let's say, in a vehicle orbiting the earth, you require something like 10, 20, 50 kilowatts of electrical power.

The only practical way of doing this, to my knowledge, if you want to keep these men up there for a month or 6 months, would be by nuclear power.

The CHAIRMAN. The ballistic missile would now appear to require chemical propulsion.

Dr. BIEHL. That is because the power is required for something like a half hour or even less.

The CHAIRMAN. And then you would expect in many instances explosions, too, of the ballistic missile.

Dr. BIEHL. That is the purpose, I take it, sir.

The CHAIRMAN. Any questions?

If not, we certainly thank you, sir, for a very fine statement.

Now we have two more witnesses this morning. We just about have time enough for them, too—that is Mr. William J. Reinhardt, head of the technical planning section of Thiokol, and Mr. John Newgard, project engineer, nuclear propulsion, of the Thiokol Chemical Co.

STATEMENT OF JOHN NEWGARD, PROJECT ENGINEER, NUCLEAR PROPULSION, REACTION MOTORS DIVISION

Mr. NEWGARD. I think I can display this chart when I have to refer to it.

In the light of what has already been said, we shall cut our talk a bit.

The CHAIRMAN. Let me ask you what happened to Mr. Levoy.

Mr. REINHARDT. He is not here today, sir.

The CHAIRMAN. The statement there has his name on it, also.

Mr. NEWGARD. That is right. He is a coauthor, but it was not necessary for him to appear. I shall briefly describe a typical nuclear heat transfer rocket, one that I feel can be developed within a reasonable period of time, and by "reasonable," I mean, as indicated by Mr. Dixon, within 5 to 10 years.

I will point out some of the problems involved in such a development program, and Mr. Reinhardt will cover various proposed uses for such systems and some recommendations.

As you have heard, one of the principal criteria for rocket performance is specific impulse. Most chemical systems operating at a chemically limited maximum temperature of about 8,000° F. can expel

gases with an average molecular weight of no more than 9, thus giving specific impulses of about 400.

A conservatively designed heat transfer nuclear rocket such as the one I will discuss, can double this specific impulse, and the performance advantages for this doubling you have already heard from Mr. Dixon.

Such a vehicle requires one to use reasonably high temperatures within the heat transfer system. I shall discuss a heat exchanger which can operate in the order of about 4,000° F.

The coolant gas through the heat exchanger is hydrogen, because it, of all the gases, has the lowest molecular weight. I should like to refer to this diagram which illustrates in cross-section what a typical heat transfer nuclear rocket system would look like. (See fig. 1, p. 166.)

This is a single-stage vehicle. It is conceivable that such a vehicle can take off from some terrestrial platform or can be launched, for example, as a second-stage after being boosted chemically. Or it is conceivable that a smaller vehicle of this type can be used as a third or higher stage in some orbital mission about the earth or in an earth-planetary mission.

Typically the rocket would contain some payload, of course, instrumentation for guidance, propellant tank, a pump, the heat source—which is the reactor—mixing chamber and the De Laval nozzle which converts the thermal to kinetic energy.

The CHAIRMAN. The upper part is the only part that is the payload, isn't it?

Mr. NEWGARD. Yes; a very small fraction of the overall weight of the system is payload, the useful part of a particular mission.

It is difficult to see from this small diagram, but if you refer to your own diagram in the paper that was handed out to you, you can see what is envisioned as the simplest vehicle. We would pump liquid hydrogen——

The CHAIRMAN. That is on page 3 of the statement, isn't it?

Mr. NEWGARD. Yes, it is figure 2. (See p. 168.)

The CHAIRMAN. Figure 1 or figure 2?

Mr. NEWGARD. Figure 2. We would pump liquid hydrogen around the periphery of the reactor through what might be a showerhead injector. At this point the hydrogen would be in a gaseous form. It would be pumped through the reactor, heated to high temperatures of the order of 4,000° F., and then expelled.

Part of the flow would be diverted to operate the pump and we would recover as much of the hot gas in thrust as we could by thrust recovery nozzles.

The control of this reactor we envision as being outside of the reactor via a scheme sometimes called reflector control. This has certain advantages over that ordinarily used to control a power reactor, where one uses poison rods—rods that penetrate the power-producing core itself.

Some of the problems involved in the development of such a machine we can briefly summarize as follows. First, a suitable fuel element must be designed and tested. This element has to be reasonably stable against corrosion and erosion. Rather large drag forces are exerted by the flowing gases on the entire core structure, if one contemplates large propellant flows through the core to obtain high thrusts. High thrusts require high-power operation of the nuclear

reactor. Hence tremendous forces are exerted on the core at the same time that high power is being generated, thus tending to disrupt and destroy the core.

An operating nuclear rocket, for example, would expel, we believe, some corrosion products. If we talk about hydrogen through the hot graphite core, there is a possibility of hydrogen combining with a carbon and forming methane in one part of the reactor, and possibly forming acetylene in another part of the reactor. These gases, methane and acetylene, are corrosion products. Surfaces and structures in the core which are corroding may be pitted, weakened, or destroyed.

High velocity flows would tend to erode and destroy the surface of the fuel elements that compose the core, just as water erodes the sides confining a stream as it flows past.

This corrosion-erosion would expel large quantities of fission products, that is, considerable radioactivity in the surrounding area, should the vehicle be launched from the ground. Even if utilized as a second stage there is some atmospheric contamination. One of the ways to completely eliminate this would be to use a nuclear rocket in orbit. In that case the radioactive material would just follow in the same orbit as the vehicle.

Another typical development problem is one of startup and of reactor control at power. How do you control such a beast? The reactor itself, for example, might operate anywhere in a power range from 100 megawatts to 100,000 megawatts, depending upon what type of mission we are talking about.

For example, a 100,000-megawatt machine in a single-stage nuclear rocket with a ground takeoff can escape from the earth with approximately 100,000 pounds of payload. No particular space mission is in mind in this example.

Hence you see for ground takeoff the control of 100,000 pounds of megawatt of power represents a considerable problem.

Another problem is that of control or the startup of such a reactor in space; for example, if you want to avoid the ground-hazard problem it is conceivable to use a nuclear rocket as a second stage, chemically boosted to space and then started in space. Here the problem is starting up this reactor relatively rapidly so it can take over when the chemical boost has lost its power.

Mr. McDonough. What would be the life of the nuclear power unit after it has been released? If you released it with the chemicals and then it got into flight, what would be the life of it?

Mr. Newgard. The life of the kinds of nuclear rocket powerplants I am discussing are all in the order of 3 to 5 minutes at very high power with maximum lifetimes for a number of conceivable missions of 1 hour. This means you can operate such plants at high power, for example, for a few minutes without running into problems, or you can operate these plants at much lower powers for longer periods of time. The operating time and power level really depend upon the mission you have in mind.

Mr. McDonough. This is all theoretical, of course. We haven't done this?

Mr. Newgard. Nobody to my knowledge has operated a nuclear rocket. I understand such tests will be performed soon.

The Chairman. Let me ask you this: In operating a nuclear rocket—that is, in building the engine, you follow fundamentally the

same principles, don't you, that you would in, for instance, operating a submarine—as I just mentioned to you earlier. The mechanical principles are there, aren't they?

Mr. NEWGARD. True, the theoretical principles are the same. But we now talk about different regimes of power operation. For most applications, at least where one wants to take large payloads from the earth, large powers are required—orders of magnitude in some cases above that of submarine nuclear reactors.

The CHAIRMAN. You would require more power to take a payload from the earth than you would to operate a submarine?

Mr. NEWGARD. Yes. Of course if you want to leave the earth with small payloads, it is conceivable you can have smaller powers. However, the nuclear rocket has been shown to have great advantages only if used for ground takeoffs with large payloads.

The CHAIRMAN. So when you are building one of these large rockets you have to program for more power than you would have in one of our nuclear submarines?

Mr. NEWGARD. Yes.

Mr. MCDONOUGH. You spoke about the maximum nuclear escape load would be 100,000 pounds.

Mr. NEWGARD. Oh, no. It is conceivable to go higher. I just talked about a single-stage vehicle capable of launching a 100,000-pound payload with roughly 100,000 megawatts of power generated in the powerplant.

Mr. MCDONOUGH. This is a mathematical calculation?

Mr. NEWGARD. Yes.

Mr. BASS. A megawatt is a million watts, isn't it?

Mr. NEWGARD. Yes. The best description I can give you of the comparable power levels is that you might compare this with the Grand Coulee power system, which to my knowledge is of the order of 1,000 megawatts.

Mr. MCDONOUGH. Well, presume we had one built that would elevate 100,000 pounds in space, what would the whole unit weigh?

Mr. NEWGARD. In the order of millions of pounds.

The CHAIRMAN. The one you are talking about there to carry 100,000 payload, you are making a comparison of the powerplant there with Grand Coulee. Correct?

Mr. NEWGARD. Oh, no; this powerplant is of the order of 100 times larger, in thermal power, than the hydroelectric power that one gets from the Grand Coulee system.

The CHAIRMAN. The thermal power in that rocket is much greater than the Grand Coulee?

Mr. NEWGARD. Yes; for this particular mission.

I have only discussed this one mission. There are other missions, for example, that one can carry out with smaller power units. Let me give you an example.

You can carry approximately 100,000 pounds into space with a nuclear-rocket powerplant, this rocket being boosted by a chemical first stage. Under these conditions the nuclear second-stage powerplant is in the order of 10,000 megawatts.

However, many different problems are now introduced. One, for example, is how to start up or bring to full power operation this nuclear powerplant while it is being boosted up by its chemical booster.

Mr. CHENOWETH. How much more power than Grand Coulee would you have to have?

Mr. NEWGARD. Roughly a factor of 10 in power from a cylinder reactor core approximately 5 feet in length and 5 feet in diameter.

Mr. CHENOWETH. Ten times the power?

Mr. NEWGARD. Yes; for the particular mission I just mentioned. The reactor system can be designed very compactly so that we can obtain as much power per given weight or volume as possible from the system.

The CHAIRMAN. Tell me this: Our technical director is making a comparison with the V–2. How much power did the V–2 generate, turn out?

Mr. NEWGARD. About 150,000 horsepower, which would be roughly 150 megawatts.

The CHAIRMAN. About 150 megawatts.

Mr. NEWGARD. Yes.

The CHAIRMAN. Is that the size of the Hoover Dam? Would you say it would be that large?

Mr. NEWGARD. I don't know. I could give you the thrust levels we are talking about. The thrust of the V–2 was about 50,000 pounds, whereas for some of the missions mentioned we are dealing in the order of millions of pounds of thrust for the nuclear vehicles.

When you want to use a nuclear rocket in space, your thrust can be much less.

The CHAIRMAN. Of course, you have got the use of nuclear energy which is very much concentrated.

Mr. NEWGARD. This is one of the very great advantages in using nuclear energy, that you can get such tremendous powers from compact systems.

The CHAIRMAN. In small areas.

Mr. NEWGARD. Small volumes.

I have indicated some of the advantages and problems that are involved in nuclear propulsion. We have elaborated these in our papers which we have given you. I will turn over the floor to Mr. Reinhardt, who will proceed with his part of the presentation.

The CHAIRMAN. All right, Mr. Reinhardt, we will be very glad to hear from you. Before Mr. Reinhardt begins, Mr. Fulton would like to ask you a question, sir.

Mr. FULTON. The question comes up on the use of nuclear power in rockets, whether you have done any experimenting on synthesizing or changing molecular structure, for example, by the use of the heat. The sun, of course, is a nuclear pile and it is changing hydrogen and helium by four hydrogen atoms to one helium, a 4-to-1 ratio. Have you done anything on the chemical approach right within your rocket of making energy on some such a change of molecular structure chemically? Have you tried anything like that?

Mr. NEWGARD. No; not in the systems I have discussed today.

Mr. FULTON. Has there been any research on the chemistry at all on, say, certain chemical compounds that are contained so that you make your energy right within the vehicle without an exhaust? Have you tried by chemical structure change to come up with energy as we get in the sun?

Mr. NEWGARD. Actually a combustion process in the ordinary rocket is a structural change. It is a reaction that occurs between an oxidizer and a fuel. But the release there is only an energy release from the

breaking and rearranging of chemical bonds. This represents but a small fraction of what one can get from a fission reaction.

Mr. FULTON. First you have the oxidizing fuels, then you have the hypergolic fuels. Then I am talking a stage beyond that and saying in this nuclear process, have you tried any of these advance changes on nuclear processes to change a molecular structure? Have you ever tried that? Is there any research being done on it?

Mr. NEWGARD. Do you mean changing chemical substances by using nuclear energy?

Mr. FULTON. That is right; in the rocket.

Mr. NEWGARD. No; we have not done any work on that.

Mr. FULTON. It would be a fruitful field of basic research.

Mr. NEWGARD. There is a substantial amount of research underway now in which one tries to use the radiations accompanying or following nuclear fission such as neutrons and gamma radiation, in order to change the structure of chemicals. But whether the synthesis of higher energy chemical compounds will result in something that is much higher than energy sources presently being synthesized by ordinary means in the laboratory, I very much doubt.

Mr. FULTON. The question is: Has there been any research done in that particular field? That is the specific one I am talking about.

Mr. NEWGARD. I think there has, but I can't be specific.

Mr. FULTON. If there has, would you put it in the record at this point?

May I ask something else. Would you comment, if you will——

Mr. NEWGARD. I can give you an answer to that earlier question of yours. A number of years ago we looked into the possibility of enhancing the energy of combustion of graphite by bombarding graphite with neutrons and hence—in our terminology—storing energy in the graphite. Hence when this bombarded graphite is burned, it generates more energy than one would normally get by just burning unirradiated graphite.

One can induce changes in energy content per gram upon burning of irradiated graphite which is between 20 to 40 percent greater than in burning unirradiated graphite. But the cost of putting this additional energy into graphite is in the order of thousands of dollars a pound and hence is uneconomical.

One would have to build special-purpose high-flux nuclear reactors loaded with graphite.

However, you can get relatively small changes in the energy content of this particular substance by exposing it to neutron radiation.

Mr. MCDONOUGH. Do you change the molecular structure of graphite when you bombard it with the neutrons?

Mr. NEWGARD. Yes; you do change it to the extent of disrupting carbon-carbon bonds. Part of the energy of the neutrons is spent in placing some of the carbon atoms in different positions in the lattice. Presumably when you now burn the graphite this additional energy which you have stored in the lattice now appears as additional combustion energy.

Mr. FULTON. The chairman and I have been very interested in a break-through on propellants looking to different designs and different combinations rather than just trying to improve the present ones.

Would you say this, that you think Russia has any superfuel that she has broken through on that we are not aware of that she might be using of this nature?

Mr. NEWGARD. No, sir; I have no knowledge of that.

Mr. FULTON. So that they, too, are at the present limit of knowledge as we are on the present fuels?

Mr. NEWGARD. I believe so.

The CHAIRMAN. May I ask you this question? I saw in the newspaper the other day the use of plain water for insulation for this nuclear reactor. Has there been much experimentation in that?

Mr. NEWGARD. You mean shielding with water?

The CHAIRMAN. Yes.

Mr. NEWGARD. This is well known in reactor technology. One does use water as a shield in certain stationary powerplants.

The CHAIRMAN. If you would use that in a rocket, would it reduce the weight?

Mr. NEWGARD. Probably not; because there are better and lighter shields than water. The rocket I discussed, for example, would contain a minimum of shielding, mostly about the important instrumentation and payload—very little about the reactor itself.

The CHAIRMAN. Thank you very much, sir. Now we will hear from Mr. Reinhardt.

STATEMENT OF WILLIAM J. REINHARDT, HEAD, TECHNICAL PLANNING SECTION, REACTION MOTORS DIVISION, THIOKOL CHEMICAL CO.

Mr. REINHARDT. We have given you quite a recitation on the problems involved in developing a nuclear rocket. We still think that it should be done. Now I am going to try to show you as well as I can why we think this.

You have heard a lot of discussion about the comparison of chemical and nuclear rockets. We have all thrown around factors of comparison. I think Mr. Dixon used 3 to 1, 10 to 1, and so on. I am going to put it in a slightly different form for a particular mission.

The numbers I am about to quote now are not the only "right" numbers that exist. They are merely representative numbers. I am going to talk a little bit about the use of a nuclear rocket to make a round trip to Mars, starting from an Earth orbit. In other words, I am presuming that we get the nuclear rocket up into an earth orbit of about 200 or 300 miles by some other means—let us say chemical means. It is up there and it capable of going to Mars.

The CHAIRMAN. Two or three hundred miles above the earth?

Mr. REINHARDT. That's right; yes, sir.

Now, a chemical rocket is also capable of going to Mars from a 300-mile orbit, but I am going to show why this is not as desirable as trying it with a nuclear rocket.

On this chart I have plotted the travel time to Mars versus the ratio of payload over initial gross weight. (See fig. 4, p. 174.)

The CHAIRMAN. Mr. Reinhardt, could you stand just a little on the other side so these members here can see you there? I believe standing on the other side that everybody will see you.

Mr. MILLER. Isn't that following page 16 of your statement?

Mr. REINHARDT. Yes; that is figure 4, I think.

This chart shows the ratio of payload to initial gross weight for the vehicle that makes the trip to Mars—starting from an earth orbit (satellite). This is not to be confused with the booster rockets used to get into orbit.

The chart shows a nuclear single-stage rocket and a chemical two-stage rocket. In this chart the nuclear is the red line and the chemical is the green line.

I have chosen round values of specific impulse, 800 seconds for the nuclear rocket and 400 seconds for the chemical rocket—just to round things off.

The chart shows that if you specify that you want to make the trip to Mars in anything less than about 5 months or so, you can't do it even with a nuclear rocket and you certainly can't do it with a chemical rocket. If you allow a greater time period like, let us say, 8 months, then the nuclear rocket can do it and roughly one-tenth of the vehicle weight will be real payload.

In the same trip time of 8 months the chemical rocket still cannot make the trip.

If we specify a longer period of time like 12 months or so, both vehicles theoretically can make the trip, but the payload of the nuclear rocket is roughly 2½ to 3 times that of the chemical rocket payload.

In other words, if we specify a certain payload, let us say 30,000 pounds, and a trip time of 12 months, with a nuclear rocket we must put 100,000 pounds into orbit. For the corresponding chemical rocket we must put up into orbit roughly 200,000 pounds.

Let me digress for a moment and give you some idea of the cost of getting that kind of weight into a 300-mile orbit. Let's assume it will cost $600 to place a pound of payload in orbit. I don't mean to imply that this $600 is a "real" figure which I can prove or which can be disproved by anybody else, I simply chose to assume it for illustrative purposes only.

We are talking here about putting up a weight of 100,000 pounds for the nuclear rocket, and 200,000 pounds into orbit for the chemical rocket.

Coming back to this figure of $600 per pound, to give you some feel for what it means, we are talking now in this country about putting into orbit values for weights of something in the neighborhood of 35,000 pounds. To do that with my $600 per pound figure will cost $21 million. If you do 10 such shots per year, it will cost $210 million, or roughly a fifth of a billion dollars. That is a lot of money.

Mr. FULTON. Did you say $21 million?

Mr. REINHARDT. I said $21 million for each shot.

The CHAIRMAN. Ten shots would be $2.1 billion.

Mr. REINHARDT. $210 million. I didn't say $2 billion.

The CHAIRMAN. $210 million for 10 shots.

Mr. REINHARDT. Yes. I just used those numbers to give you some idea of what we are talking about in terms of dollars. I showed you that to do a Mars mission with a nuclear rocket you have to put up roughly one-half or one-third of the weight that you must put up into orbit if you use a chemical rocket.

The CHAIRMAN. So your chemical rockets there would run really, instead of $210 million to handle the same payload, would run $420 million to $640 million; isn't that right, in 2½ to 1?

Mr. REINHARDT. There is roughly a 2½-to-1, or 3-to-1, advantage for the nuclear rocket I should add that in this example I chose a conservative nuclear rocket, or one which is relatively unsophisticated,

if you will. It has roughly a 2-to-1 advantage over the chemical rocket.

The cost of placing both the nuclear- and chemical-powered Mars vehicle in orbit will be discussed next.

On this next chart (fig. 5, see p. 175) in your writeup, I show that in order to get the 30,000-pound Mars payload into orbit we are talking about figures of something like $120 million for the chemical rocket and something in the order of $60 million for the nuclear space vehicle. It should be noted that these are just the costs for getting the actual 30,000-pound Mars payload and the space vehicles into orbit.

So just before we start our trip to Mars—from an orbit around the Earth—we have a cost differential of something like 2 to 1 and with my assumed valuation of $600 per pound, it is something like $60 million or so.

Now, in order to say with finality that the nuclear rocket is better than the chemical rocket, I should be able to tell you what this vehicle will cost—that is, the vehicle that takes us from an Earth orbit to Mars and back. I can't do it now.

The reason is that there just is not enough engineering data to make any kind of cost prediction which would make sense.

That is all I have to say about the application. We could talk about a lot of other missions but that won't be necessary because the one I have chosen is a typical one and I think a good one.

Finally, I will conclude by saying we at Thiokol think the nuclear rocket should be pursued in an industrial development program, with somewhat more speed than we have on it right now.

Mr. McDonough. Your point is that a nuclear rocket is more economical insofar as long interplanetary missions are concerned than the chemical rocket?

Mr. Reinhardt. I have to qualify that, sir. I do say that to get the nuclear rocket to the starting place, to the place where it would begin a space voyage, is definitely cheaper. What the final overall cost is, I can't say at this time because I have no way of logically estimating the cost of the nuclear vehicle that would actually make the trip from an Earth orbit to Mars. There is just not enough engineering data to do that.

Mr. McDonough. From a practical point of view, how much progress have we made on a nuclear rocket up to the present time?

Mr. Reinhardt. Mr. Dixon, I think, gave you a fairly good rundown on that. The chief effort is the research effort at the national laboratories right now, and some of the rocket companies are doing component work in support of that program.

The Chairman. Will the gentleman yield?

The tests that are going to be made—when is that, this summer?

Mr. Reinhardt. Sometime this year. There will be a test this year and perhaps another one next year. A positive statement can't be made about our progress until those tests are over.

Mr. McDonough. Where will those tests be made?

Mr. Reinhardt. In Nevada.

The Chairman. Does your company have the brainpower, that is, the engineers and the scientists, which would be needed to pursue the nuclear program?

Mr. Reinhardt. Yes, sir. Like other companies, Thiokol does have manpower, qualified manpower, which it could put on this program.

The CHAIRMAN. You could divert them. They would be available to you?

Mr. REINHARDT. Yes, sir.

The CHAIRMAN. And you think they have the ability and the background sufficient to go ahead and produce a nuclear rocket?

Mr. REINHARDT. Yes, sir.

The CHAIRMAN. If given the green light and enough money to do it?

Mr. REINHARDT. Yes, sir.

The CHAIRMAN. How long do you think it would take to do it?

Mr. REINHARDT. I have to hedge a bit and say it would take somewhere in the neighborhood of 4 to 8 years. I can't be more specific than that.

The CHAIRMAN. Of course everybody knows yours is a guess there. You are estimating something that doesn't exist. Mr. Chenoweth.

Mr. CHENOWETH. I wanted to ask if there is any immediate military application that you can use the nuclear rocket for?

Mr. REINHARDT. No, sir. A nuclear rocket, per se, doesn't have any worthwhile military application, from what we can see right now.

Mr. CHENOWETH. It is no better than the chemical then?

Mr. REINHARDT. That is right.

The CHAIRMAN. What about the nuclear rocket in orbit? Would you say that had an advantage?

Mr. REINHARDT. At this time I couldn't prove that it had an advantage.

Mr. CHENOWETH. There is no military advantage if you are going to Mars on this kind of trip. I am talking about something we need right now. You don't have anything at all, there has been nothing, no progress made?

Mr. REINHARDT. No, sir. In general I think that immediate military requirements can be adequately handled with chemical systems.

Mr. CHENOWETH. Is that going to take 4 to 8 years to develop something like that in case you decided it would be wise——

Mr. REINHARDT. You mean for military application?

Mr. CHENOWETH. Yes.

Mr. REINHARDT. If you ever saw a military application where it would do some good, it would take that long; yes.

Mr. CHENOWETH. You don't think it has any possibilities at all?

Mr. REINHARDT. That is a pretty broad statement, but I'll go out on a limb and say that I don't see any really worthwhile military applications now.

Mr. CHENOWETH. Up to now, at least, you haven't revealed anything, uncovered anything.

That is all, Mr. Chairman.

The CHAIRMAN. Let me correct something. One of the witnesses said something about the use of nuclear power for orbiting. That indicated an advantage. Who was it who referred to that? What about that?

Mr. DIXON. Whereby you would like to place a large payload in an orbit, the nuclear rocket, I think, can do it with a smaller sized rocket. We are talking in the order of hundreds of thousands of pounds that you would like to place in an orbit.

The CHAIRMAN. Of course it is a different type of proposition that you have in mind, isn't it, where you would put the rocket in orbit

for a particular reason, and you feel like the nuclear powerplant would be more efficient?

Mr. DIXON. Yes; the nuclear rocket would be more efficient. One possiblility where you would like to place maybe a half million pounds in a day orbit—that is, an orbit which rotates at the same rate the earth rotates, and a nuclear rocket would look very attractive from the point of view of the size and the weight to accomplish this mission.

The CHAIRMAN. Mr. Fulton.

Mr. FULTON. The question comes up with your recommendation that there be a larger program for nuclear rockets and missiles; in what order of magnitude are you thinking? How much more money would you say and in what fields and in what period of time? If you would like to put that in the record later on, you can do it.

Mr. REINHARDT. The answer to that is it depends on many things.

Mr. FULTON. I will ask the witnesses who are here this morning to put a comment in the record, rather than to go into it now.

Mr. REINHARDT. You would like that in the record afterward?

Mr. FULTON. Afterward. Submit it for the record.

The CHAIRMAN. There were some questions along that line. I think one of the witnesses said, to push this program, they should have double the amount of money they have available for research and development.

Mr. FULTON. I have asked about the approach and also the timing.

The CHAIRMAN. Anyway, if you could, we would appreciate your supplying that.

(The material requested is as follows:)

REACTION MOTORS DIVISION, THIOKOL CHEMICAL CORP.

I believe that the current nuclear rocket program could be augmented as follows:

	Million
Overall increase in budget, 1st year	$10
Areas:[1]	
1. Complete design study of flight system	4
2. Initiate basic facility work (planning and initial procurement)	2
3. Initiate fabrication and development of nonreactor components (e.g., controls, pressure vessel, nozzles, etc.)	2
Overall increase in budget, 2d year	50
Facilities	10
Reactor development	20
Nonreactor development	20

[1] Sic.

The CHAIRMAN. Any further questions?

Mr. DADDARIO. Just one question. Mr. Dixon, when you mentioned in your talk that one of the problems is the contamination from radiation, and if we got this vehicle out into orbit and then used the nuclear powerplant there and then you would be in outer space, are you under the same problem of contaminating outer space and run into the same situation there, just transferring the problem from the earth's atmosphere?

I understand there is a lot of space, but we expect eventually we will be out there and there will be the same problem.

The reason I asked you: Isn't this one of the things that is holding back the whole nuclear development program really, in this area—what to do with radiation, what to do with the waste and all that type of thing? Psychologically, there seems to be a barrier as a result of this particular type of problem.

Mr. NEWGARD. As far as putting radioactive material in space, there are, at least in the further reaches of space, very recently discovered radiation belts, and I doubt that nuclear contamination would mean anything in these particular regions.

I suppose you could contaminate a very minute area in space if you are talking about an orbiting nuclear vehicle, which, for example, will use power to move from orbit to orbit. But that would be such a minute fraction that I don't think it could cause you any difficulty in the future.

Mr. DADDARIO. We are talking about one vehicle which will eventually lead to many, many others and eventually——

Mr. NEWGARD. The volume of space is so huge that I imagine you cannot contaminate it even by sending hundreds and hundreds of vehicles.

Mr. DADDARIO. My question gets to the point of contamination generally. Do you think that there is a psychological barrier because of the fear that there is now existing about the radiation problem?

Mr. NEWGARD. If the radiation is pretty much confined to a specific area, areas for the tests of these vehicles and their actual firing, is pretty much confined, if we are now talking about a nuclear rocket which is fired from the earth, it can be much less than that of the kind of contamination that we throw into the atmosphere every time we fire a bomb.

Let me give you an example. We have done some calculations and have shown that the fraction of fission products which you would throw into such a site if you corroded 1 percent of nuclear rocket core which is to carry up a large payload into space would only be a few percent of the kind of contamination you would get if you fired a conventional type of atomic bomb.

Mr. DADDARIO. Then if you proceed with this program, enlarge it, and get to the point where you could do the research and development, then the danger of radiation is very, very small in this proportion which you have just illustrated.

Mr. NEWGARD. I believe it would be small, barring, say, a major accident, a major release. It is conceivable that a nuclear rocket can, as Mr. Dixon indicated, melt down and this would release fission products in an area.

But barring such a major release, it is believed that the contamination problem will be small.

Mr. DADDARIO. Barring that type of catastrophe, then, you feel that this kind of program could go ahead and could proceed with dispatch and with safety?

Mr. NEWGARD. I believe so.

(The prepared statement of Mr. Reinhardt, Mr. Newgard, and Mr. Levoy is as follows:)

PREPARED STATEMENT OF W. J. REINHARDT, CHIEF TECHNICAL PLANNING ENGINEER; J. J. NEWGARD, PROJECT ENGINEER, NUCLEAR PROPULSION; AND MYRON LEVOY, PROJECT ENGINEER, NUCLEAR PROPULSION, THIOKOL CHEMICAL CORP.

HEAT TRANSFER—NUCLEAR ROCKETS FOR SPACE FLIGHT

I. INTRODUCTION

A nuclear heat transfer rocket is one in which the energy source and ejected "working fluid" are separate entities. It will be recalled from earlier presentations that in a chemical rocket both the energy source and working fluid are provided by the same entity, namely, the propellants. It is the separation of energy source and working fluid which gives the nuclear rocket its unique performance characteristics.

The chief performance characteristic in rocket propulsion is specific impulse. The weight of the propulsion hardware is also significant, but in many applications of both chemical and nuclear propulsion, specific impulse is the dominant performance characteristic.

Specific impulse can be defined in a variety of ways. The most common definition being:

$$\text{Specific impulse} = \frac{\text{Thrust (lbs.)}}{\text{Working fluid flow rate (lbs./sec.)}}$$

However, another definition, namely

$$\text{Specific impulse} = \frac{\text{Working fluid/exit velocity (ft./sec.)}}{\text{Gravitational constant (g—ft./sec.)}}$$

is more revealing, in that it shows that specific impulse is simply a measure of the working fluid velocity and hence kinetic energy.

Still another set of mathematical manipulations shows that specific impulse is proportional to the square root of working fluid temperature and inversely proportional to the square root of working fluid molecular weight or

$$Isp = \text{constant} \sqrt{\frac{\text{Temperature (° R.)}}{\text{Molecular weight (lb./mo.)}}}$$

This equation shows us that in order to attain higher values of specific impulse, we must raise the temperature and/or decrease the molecular weight.

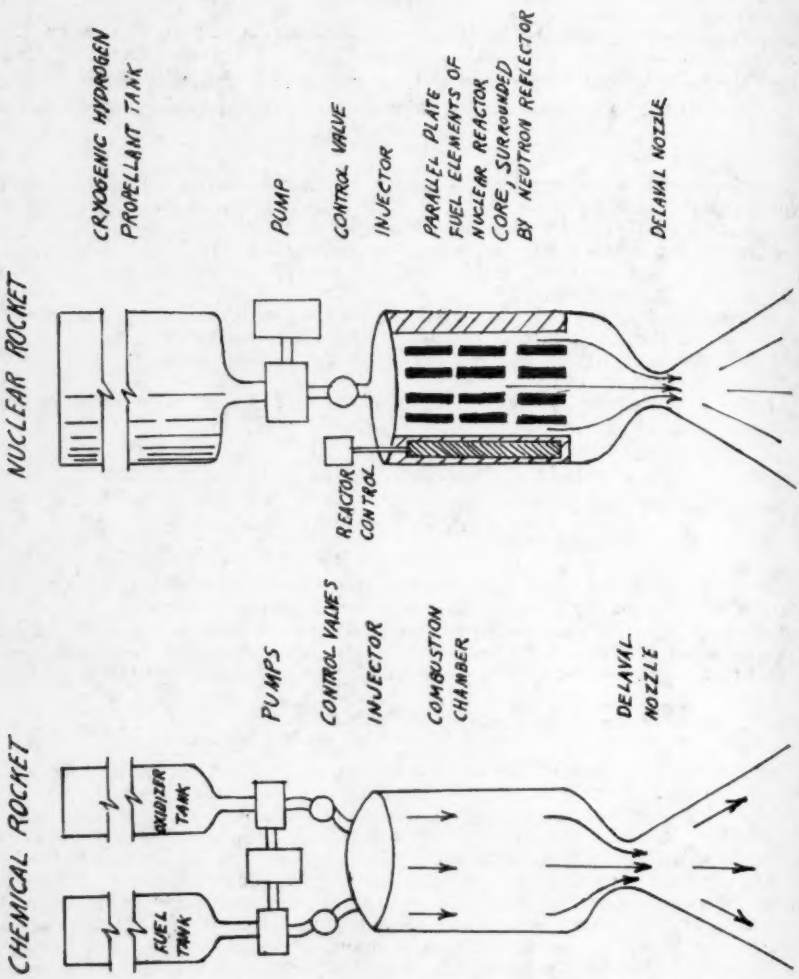
In chemical rockets the combustion temperature and molecular weight of the working fluid are intimately tied together by the chemistry of the combustion process. Maximum attainable temperatures run as high at 8,000° F., and the minimum practical values of molecular weight is around 9. These two values do not necessarily occur in the same combination. In essence, the restrictions of molecular weight and combustion temperature confine the chemical rocket to a maximum specific impulse of about 450 seconds.

In the nuclear rocket where energy is not obtained from a combustion process, the molecular weight is no longer a function of the energy production process. Hence a lightweight fluid can be used. In fact, the lightest fluid known, namely, hydrogen, with a molecular weight of 2, can be used.

In order to utilize such fluids we need to substitute a reactor for the usual chemical combustion chamber, as shown in the right of figure 1.

(Fig. 1 is as follows:)

FIGURE 1



Chemical and nuclear rocket simplified diagrams show the substitution of a reactor for the chemical combustion chamber.

In such a scheme, hydrogen stored at about —420° F. in the tanks is pumped to a high pressure and forced between the fuel elements of the reactor. The heated gas then expands through the nozzle, just as it does in the chemical rocket. The basic difference lies in the use of the self-contained, heat-generating unit, the nuclear reactor, in the "combustion chamber."

We have seen that the nuclear rocket can use very light working fluids, thus freeing it from one of the restrictions on chemical rockets. Now what about the other important element, e.g., temperature?

The attainable gas temperature, of course, depends on the temperature of the fuel elements. The precise maximum fuel elements temperatures cannot be stated at this time because it depends on the materials which we can use. Since these materials are still being investigated on a research basis, no firm temperature figure can be stated. However, even if we can only produce gas temperatures of 4,000° F., we will have doubled the attainable specific impulse of chemical rockets.

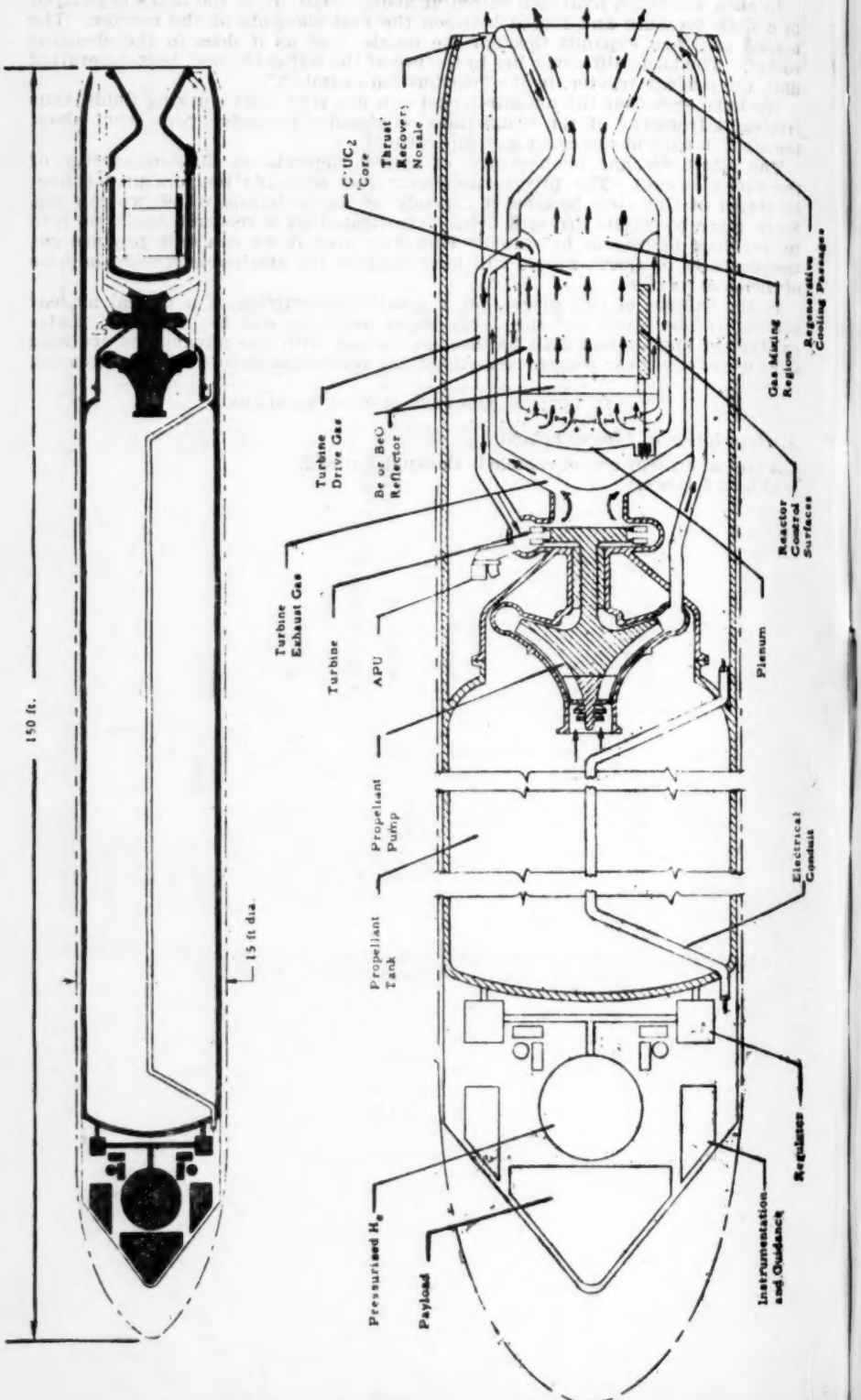
In the balance of this discussion, a detailed description of a typical nuclear vehicle will be given and the development problems will be discussed. Later on, typical applications will be discussed along with the advantages accruing from use of a nuclear rocket. Finally, a few recommendations will be presented.

II. DETAILS AND DEVELOPMENT PROBLEMS

A. Description of typical vehicle

A typical nuclear rocket vehicle is shown in figure 2.
(Fig. 2 follows.)

FIGURE 2



Schematic diagram of a nuclear rocket.

Liquid hydrogen is stored in insulated tanks equipped with "blowoff" valves that relieve excessive pressure. Pressurized helium replaces hydrogen as it is drawn off to propellant turbopump.

Hydrogen at high pressure (10^3 p.s.i.a.) flows from pump through ducts to exit end of rocket nozzle, where it is used to cool nozzle and reactor chamber walls before entering plenum.

Most of hydrogen then flows down through reactor and out DeLaval nozzle at 4,000 F. Small amount of hydrogen is diverted at plenum to cool reflector and structural columns. Gas leaving reflector at 1,500 F. and 350 p.s.i.a. is used to drive turbine of turbopump. Bypass valve affords turbine control. Turbine exhaust gas is expelled through thrust-recovery auxiliary nozzles.

The above nuclear rocket is most useful as a first- or second-stage booster to carry larger payloads into orbit or space.

B. Reactor type

The reactor which we would choose for early development is an open-cycle, solid-fuel-core type. Much experience has already been accumulated with solid-fuel elements developed for reactors for stationary powerplant application.

A simple heat exchanger application of this core is envisioned in which the propellant is heated to high temperature as in an ordinary reactor. Although such a reactor scheme appears unimaginative, it is one that we have confidence we can build today.

The considerations of low-weight reactor cores capable of operating at the very highest temperatures compatible with sound structure and at reasonable fissionable material loadings, leads to the choice of low-molecular-weight ceramics or ceramiclike material such as graphite.

In terms of high-temperature strength, resistance to H_2 and neutron absorption, graphite seems to be the best of these materials for temperature of 4,000° F. and 5,000° F. Lower thermal stresses occur in graphite than in other ceramics. In addition, graphite's thermal conductivity is quite good compared with other ceramics, permitting higher exit gas temperatures for a given fuel-element thickness or diameter.

Graphite systems of small size, suitably reflected, can be constructed which are essentially thermal. Such systems can be designed reasonably small with large amounts of excess reactivity required to compensate for certain operating contingencies, such as losses of core material, changes in propellant density, etc.

Low-molecular-weight propellant gas (which serves as reactor coolant) makes the choice of H_2 inevitable if any appreciable specific impulse increase over the best chemical systems is to be attained. For example, use of CH_4, NH_3, or He would give approximately half the specific impulse of a H_2 nuclear rocket operating at the same temperature.

The reactor core design is governed by the mission to be performed, at maximum heat transfer and fluid flow consistent with a structurally stable system. For a solid-core nuclear rocket reactor with definite temperature limitations (e.g., graphite limited to about 5,000° F.), maximum specific impulses of the order of 800 can be obtained. This is an improvement of about 100 percent over the best chemical systems.

C. Fuel element design

Developing a satisfactory fuel element is first on the list of problems. One starts with one of the high-temperature materials, such as graphite, as combination moderator and matrix for the uranium fuel. Then it is necessary to fabricate this mixture into shapes rugged enough to withstand violent thermal and mechanical stresses and yet thin enough to minimize thermal gradients and provide adequate surface area. Some possible fuel element shapes are shown in figure 3. With other things equal, the design with the smallest pressure drop is preferred.

(Fig. 3 follows.)

FIGURE 3

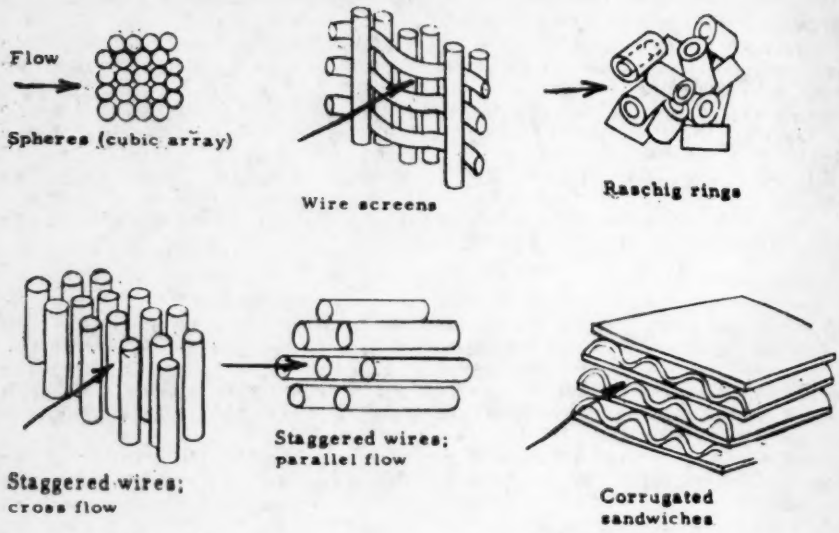


FIG. 3 POSSIBLE CORE ELEMENT CONFIGURATIONS
Dwg. 48602

Comparison of Several Core Element Configurations.

Core Element Configuration	Pressure drop through core normalized to 1.0 for best configuration.
Raschig rings	78
Spherical pellets	67
Stacked vertical wire screens	51
Staggered wires, cross flow	41
Corrugated sandwiches or flat plates	~1.0
Staggered wires, parallel flow	~1.0 excluding spacers

It was found that rod elements and parallel flat plates arranged in bundles gave lowest pressure drops under the severe operating conditions of the core. Flat plates were found to be superior to rods because of the simpler spacer arrangement and less flow blockage due to the spacers.

D. Reactor core design

Because of security restrictions, only the most general features of a nuclear rocket are described. A cylindrical solid-fuel-element reactor illustrates all the basic features of a nuclear powerplant for rocket propulsion. The reactor core might consist of a large number of parallel plate fuel elements which may be made of uranium-loaded graphite.

Plates may be unclad or may utilize a coating, depending on erosion and corrosion considerations. The plates are stacked together in bundles and are separated by small cylindrical protrusions or buttons on the surface of the plates. The plates may be bound together in the bundle by drawn tungsten or molybdenum wire, banding each bundle at several points.

This metal must be held to a minimum. Stress analysis of the bundle has indicated that under design conditions it would remain integral. The fuel bundles may be further held in position by means of graphite cross braces and lateral supports. The matrix would transfer the pressure-drop load to metallic tubular tension columns (which are supported from the cold end and run the length of the core) and to the rocket outer wall.

The tension columns would be cooled with liquid hydrogen flowing internally and would be made of a high-temperature metal like molybdenum. The total amount of such material would have to be kept small for a reasonable critical mass.

The plate element thickness is limited by thermal stress considerations. (Stress relief resulting from plastic flow may permit thicker elements.) The thickness of the element is constant within a given bundle, but varies from bundle to bundle in the axial direction.

A simple design would utilize a constant void fraction through the core. (Void fraction=flow area/total area.) This results in a rapidly increasing pressure drop as the gas approaches the hot end of the reactor, particularly at low values of void fraction. The increase in pressure drop is almost exponential.

A more complex design might utilize a variable void fraction through the core (higher void fraction at the hot end, lower at the cold end). Such variation would reduce the overall pressure drop across the core without introducing much additional fabrication difficulty. Also, a saving in core structural weight might be effected due to lower coolant drag forces on the structures.

The design at each point through a typical graphite reactor is limited by three considerations: (1) Maximum allowable graphite plate temperature must be below about 5,000° F.; (2) the thermal stress in the plate may not exceed the allowable stress; (3) the minimum plate thickness must be held to some reasonable level, perhaps 30 mils, from fabrication and rigidity considerations.

E. Reactor control design

In the scheme of reactor control that we visualize, the reflector would act as a variable source of thermal neutrons controlled by reflector changes. Large reactivity changes can then be effected by reflector motion to be made available as required during powerplant operation.

The difficulties in utilizing core-inserted poison control rods also leads to our adoption of reflector control. Also, core rods lead to more difficult cooling problems than reflector drums. They must be vertically removed and inserted, tending to make the overall system less compact. They must operate in a high-temperature region subject to some destruction. This may lead to control rod channel blockage. In addition, core rods occupy valuable volume which might otherwise be occupied by fuel elements.

The control of the nuclear reactor is accomplished by means of stainless-steel control plates containing boron, stationed around the reactor core within the BeO reflector. The plates are curved portions of right cylinders. The plates must be cooled due to the heating accompanying capture of neutrons by the boron and consequent α-particle emission. Each plate is completely jacketed by a metallic shroud which is tacked to the plate giving it added stiffness in bending.

The BeO reflector blocks are machined to take the control plate assemblies. The plates drop into curved slots in the assembled BeO blocks. A plate passes through all the BeO blocks to the lowest one, where the bottom of the plate rides

in a bearing race. Control is achieved by means of a mechanical drive system geared to the shaft.

When the plate faces in toward the reactor core, the BeO reflector is cut off from the core neutrons in part by the borated surface. As the plate is rotated out, more fast and slow neutrons can enter the reflector. Some slowing down occurs there and most of these neutrons are returned or reflected to the core. Hence, the power level of the reactor may be controlled by the movement of these plates.

F. Some dynamic operating considerations

A suitable safe reactor period must be chosen by an optimum manipulation of the control plates. Fluid flow rates will gradually increase as temperatures of the core increase consistent with structural stability, until at criticality the final steady-state temperature through the core is established.

Power increase to required operating level can now occur by increasing the fluid flow rate. This must be done rapidly to avoid propellant waste. The reactor will have to be carefully coupled with the control of turbopump and valves. It is felt that considerable experience will have to be gained before fast safe startups will become practical.

During power operation (perhaps sooner) various reactivity changes will occur due to changes in the material composition of the core. The following reactor core changes were considered as possible:

(1) Reactivity change due to change in hydrogen density in the core void volume.

(2) Uniform decrease in the solid volume of the core (including both fuel and moderator) due to corrosion or erosion of the system.

(3) Nonuniform decrease due to destruction of a plate or bundle in the core matrix and its consequent discharge out of the core by the propellant gases.

A large positive reactivity change is associated with even small changes in the hydrogen density in a core of small size. Control of small density fluctuations will pose severe problems since this control is also important in burnout considerations. At present it is felt that reflector control provides enough excess reactivity to compensate for core destruction during operation if this destruction is less than 20 percent of the core volume.

G. Hazards

The propellant choice, itself, presents a problem. While hydrogen is desirable from a rocket performance viewpoint, the cryogenic difficulties are considerable. Logistics may demand a propellant which is easily transported, stored, and transferred to the rocket tanks. Fire hazard with hydrogen can be a problem.

Hot hydrogen, exhausted from the rocket during a ground takeoff, might burn or be explosive, depending on the overall composition and temperature of the hydrogen-ambient air system. It is possible that a hydrogen production plant would have to be located at the rocket-launching site to alleviate problems of hydrogen transportation and storage.

Because of the relatively short-thrust lifetime, problems of shielding and radiation damage at full power, as well as the afterheat removal problem, are less severe than in conventional reactors. Under these conditions it is expected that burnup and neutron damage to reactor structure will be slight.

Shielding of sensitive components or personnel will be an important consideration. Lower dosages at the payload can be achieved at the cost of an increase in shield weight.

The principal radiation ground takeoff hazard problem in graphite reactors seems to be due to corrosion and erosion of the graphite core structure and some core destruction. Coatings may be developed to prevent corrosion-erosion to some extent. Corrosion and erosion probably will occur during all reactor-operating regimes and will be severe during high-power, high-temperature operation.

Unless the nuclear rocket can be placed in orbit before reactor power operation, the same hazard problems will have to be faced. For example, it is conceivable that a second or a higher stage nuclear rocket boosted off the ground to avoid ground hazard problems and started in space can fail and fall back to earth. The only certain way to avoid this seems to be to place the nuclear vehicle in a safe orbit before startup. An orbital startup, or for that matter any space nuclear rocket startup to power operation, then poses a whole new array of problems.

III. APPLICATIONS

Having heard our recitation of the development problems, you may be asking the question, "Why bother?" and you may be saying to yourself, "All that work only to double the specific impulse—not worth the effort."

In addition, you may be inclined to dismiss the nuclear rocket on the grounds that the improvement offered does not compare with the improvement obtained in the development of the A-bomb.

Before you start such a train of thought, we would like to point out a few of the facts of life connected with space propulsion. Specifically, we'd like to talk a little about the cost of the space business and the feasibility of some of our missions.

Now, heretofore, propulsion systems have been compared largely on the basis of weight, size, and reliability. These parameters offer impressive comparisons, but in our opinion they tell only half the story. We believe that weight, size, and reliability are important, but principally as means to an end.

The most significant end product of these parametric studies, from a national viewpoint, are cost and in some instances feasibility. If we rely solely on current chemical propulsion schemes, some missions become prohibitively expensive, or physically unfeasible because of either sheer size or excessive cost.

In order to illustrate these points, we need to do a little arithmetic. In order to get some fuel for the problem, let's assume that the cost of placing a pound of payload in a 300-mile orbit is $600. At this point, we want to emphasize that this is a figure assumed for illustrative purposes only.

It can be moved around quite a bit, depending on the technical approach. We now talk seriously about orbital payloads of 35,000 pounds. Coupling these two figures, we see that to get one such payload in orbit with current propulsion systems, we must spend $21 million. We don't know how many 35,000-pound payloads we'll want to put in orbit in 1 year, but we would not be surprised if we wound up putting up, say, 10 per year.

If it turns out to be 10 per year, we can expect a yearly expenditure of $0.21 billion. We think this is about 0.5 percent of our current defense budget.

Now, if you think that placing ten 35,000-pound payloads in orbit per year is too ambitious, remember that 3 years ago we talked about a few 20-pound payloads and we are now preparing Project Mercury with a 2,000-pound payload. That represents a hundredfold increase in ambition. Since a 35,000-pound payload is only 1.7 times as great as our current plan for Mercury (Man in Space), it doesn't seem too unreasonable.

If we have to put up 100 per year instead of 10, the total cost is about $2.1 billion, or 5 percent of the defense budget. Then the project may become unfeasible.

In considering the foregoing figures, bear in mind that they were given in connection with a 300-mile orbit. For interplanetary travel, the 300-mile orbit is just the first step.

Now let's consider what can be done about such costs and how the nuclear rocket might fit in. However, before proceeding let us demonstrate the importance of improved specific impulse in connection with cost.

We used an assumed reference figure of $600 per pound with current propellants. If we substitute a high-energy combination in just the top stage, thus improving the top-stage specific impulse by about 150 seconds, we can cut the cost of a pound of payload to $480. Then 10 shots per year costs only $0.17 billion, and 100 shots per year costs $1.7 billion. These figures are approximately 80 percent of the original figures based on current propellants. From these figures we see that even 150 seconds' improvement pays big dividends.

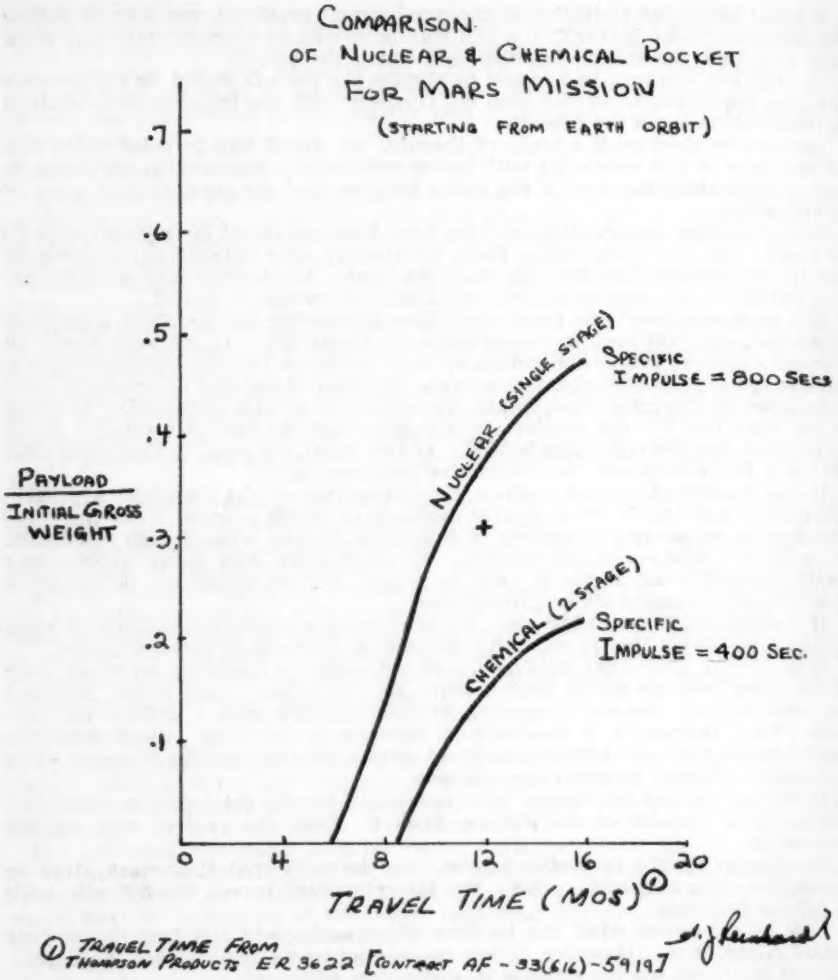
Now, where does the nuclear rocket fit in, remembering that its specific impulse is about 400 seconds greater than the advanced chemical propellants? Well, first it can be used to get from an orbit around the earth to any other planet. Secondly, it can be used on top of one or more chemical stages to get into orbit. Thirdly, it can be used as a booster to get off the earth's surface.

Let's consider the mission in which the nuclear rocket is used to get from an earth orbit to another planet. Figure 4 shows the payload-to-gross-weight ratio for such vehicles designed for a trip to Mars.

(Fig. 4 follows.)

41260—59——12

FIGURE 4



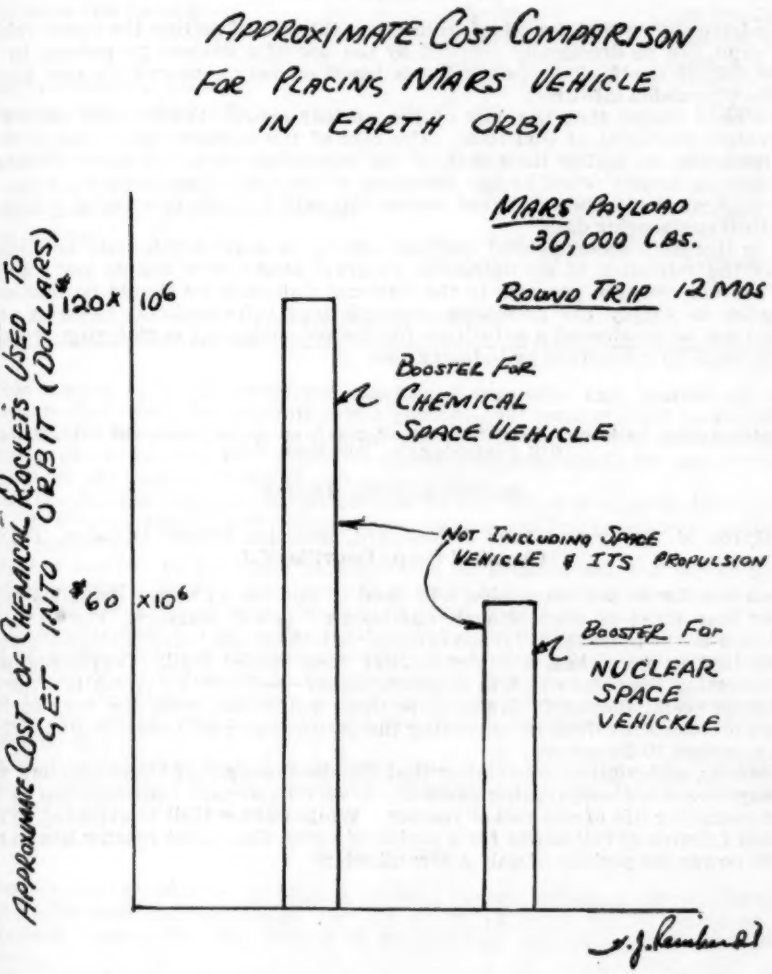
The figure shows that if we specify a trip time of less than 5 months, then neither the nuclear or chemical rocket shown can make the trip. It also shows that for trip times between 5 and 8 months, of the two rockets shown, only the nuclear vehicle can make the trip.

Beyond 8 months, both vehicles can make the trip, but the nuclear rocket can carry more payload. The percentage advantage of the nuclear rocket over the chemical rocket shown is highest at 8 months and decreases to about 2½ to 1 at about 16 months. The cross illustrates a relatively conservative nuclear rocket which can carry twice as much payload as the chemical rocket for the same gross vehicle weight and trip time.

From the figure we see that if we specify a trip time of 12 months, roughly 30 percent of the nuclear vehicle is payload, while only 15 percent of the chemical vehicle is payload. Hence, if we wish to send a 30,000-pound payload to Mars, we must put in orbit a 100,000-pound nuclear vehicle or a 200,000-pound chemical vehicle.

Referring again to our assumed figure of $600 per pound of orbital payload, we see that it will cost $60 million to get the nuclear-powered vehicle in orbit and $120 million for the chemical vehicle. This represents a 50-percent reduction in the cost of getting into orbit with our 30,000-pound Mars payload. This is shown in figure 5.

FIGURE 5


APPROXIMATE COST COMPARISON
FOR PLACING MARS VEHICLE
IN EARTH ORBIT
MARS PAYLOAD
30,000 LBS.
ROUND TRIP 12 MOS
APPROXIMATE COST OF CHEMICAL ROCKETS USED TO GET INTO ORBIT (DOLLARS)
$120 X 10^6
$60 X 10^6
BOOSTER FOR CHEMICAL SPACE VEHICLE
NOT INCLUDING SPACE VEHICLE & ITS PROPULSION
BOOSTER FOR NUCLEAR SPACE VEHICKLE

Now this is not the whole story. We should proceed to estimate the cost of the space vehicles themselves. Unfortunately, we cannot make a meaningful comparison because the ultimate cost of the nuclear rocket cannot be predicted with accuracy. An accurate cost estimate must be delayed until such time as we have more engineering data available.

It should be noted that, had we specified a shorter trip time, both approaches would be more expensive; but the advantage of the nuclear vehicle over the chemical vehicle would have increased.

In considering the foregoing comments, it is important to bear in mind that the cost estimates are very crude and that the chemical rocket is in a much higher state of development. The uncertainty about the nuclear rocket performance is directly due to the lack of truly applicable engineering test data.

As mentioned earlier, the nuclear rocket may also be used to place a pay-

load in orbit around the earth either in a single- or multi-stage vehicle. When used in a multistage vehicle, the booster may be a chemical rocket. In any such application, a significant reduction in vehicle weight will result. However, the possibility of reactor failure poses a significant hazard problem. Again there is not sufficient engineering data to evaluate solution to these problems.

IV. RECOMMENDATIONS

We have shown that for a typical mission, the cost of getting the space vehicle into orbit can be drastically reduced by the use of a nuclear propulsion in the space vehicle itself. This conclusion is based on very conservative cost figures for the propulsion into orbit.

We have stated that the cost of the nuclear space vehicle itself cannot be accurately predicted at this time. The cost of the nuclear space vehicle itself will probably be higher than that of the equivalent chemical unit. However, this may be largely offset by the reduction in the cost of getting into orbit. At this time we don't know to what extent this will be true because of a lack of practical engineering data.

It is therefore recommended that our efforts to acquire this data be stepped up by the initiation of an industrial program aimed at a usable test vehicle. The current research program in the National Laboratories should be continued in order to supply the necessary research type information. However, this should not be considered a substitute for the recommended engineering program which could be carried out by industry now.

[Reprinted from Nucleonics, July 1958, vol. 16, No. 7, pp. 66–68, copyright 1958, McGraw-Hill Publishing Co., New York, N.Y.]

Rocket-Reactor Design

By Myron M. Levoy and John J. Newgard, Reaction Motors Division, Thiokol Chemical Corp., Denville, N.J.

Reactors for rocket propulsion will need to operate at power densities much higher than those of conventional "earthbound" power reactors. For example, as shown in the table (p. 177), one is trying to extract 100 times more power from a core that is more than 30 times smaller than Calder Hall. Correspondingly the operating temperatures will be much higher—~4,000° F., typically. Such a goal must seem completely fantastic to those acquainted with the very serious design problems involved in improving the performance of a reactor like Calder Hall a modest 10–20 percent.

However, although no one claims that the development of these reactors will be easy, there are extenuating factors. A very important consideration is the short operating life of the rocket reactor. While Calder Hall is expected to run without failures at full power for a period of years, the rocket reactor has to run at full power for periods of only a few minutes.

Design Figures for a Nuclear Rocket Reactor

	Calder Hall	*Nuclear Rocket**
Total power [Mw(th)]	182	5×10^3–5×10^4
Core shape and dimensions	cylinder diam: 31 ft length: 21 ft	right cylinder diam: 4–8 ft length: 4–8 ft
Core power density (kw/ft³)	11.5	5×10^4–5×10^5
Mean core temperature (° F)	461	~2,000
Coolant	CO_2	H_2
Coolant flow rate (lb/sec)	1,964	500–4,000
Coolant temperature rise (° F)	353	~4,500
Coolant pressure drop through core (psi)	6	~1,000
Core lifetime	fuel: ~4 yr structure: ~20 yr	2–15 min

* Total thrust 4 to 30×10^5 lb, specific impulse ~750 sec.

This means rates of structural creep and corrosion and erosion of core materials that would be prohibitive in a conventional reactor could be tolerated in a rocket. Reactivity loss due to burnup and fission-product poisons would be insignificant so that any available excess reactivity could be used to compensate for the nuclear effects of corrosion-erosion.

Also the designer of a nuclear rocket reactor can afford to be much less finicky about how much radioactivity the reactor releases (as compared with ordinary power reactors).

Since a nuclear rocket could be fired from an isolated site and would spend most of its operating life far above the atmosphere, a certain amount of radioactivity release could be accepted as a standard operating condition. (From a worldwide viewpoint, any contamination would be negligible. At burnout the core of a reasonably sized rocket reactor would contain in total less than a few percent of the fission products released by a 20-kiloton atomic bomb. Since even under the worst conditions only a small fraction of these products would actually escape, the total contamination should be insignificant compared with an atomic bomb.)

Insofar as the performance of ordinary reactors is limited more by considerations of safety than by the possibility of gross structural failure, this gives nuclear rockets additional edge.

REACTOR TYPE

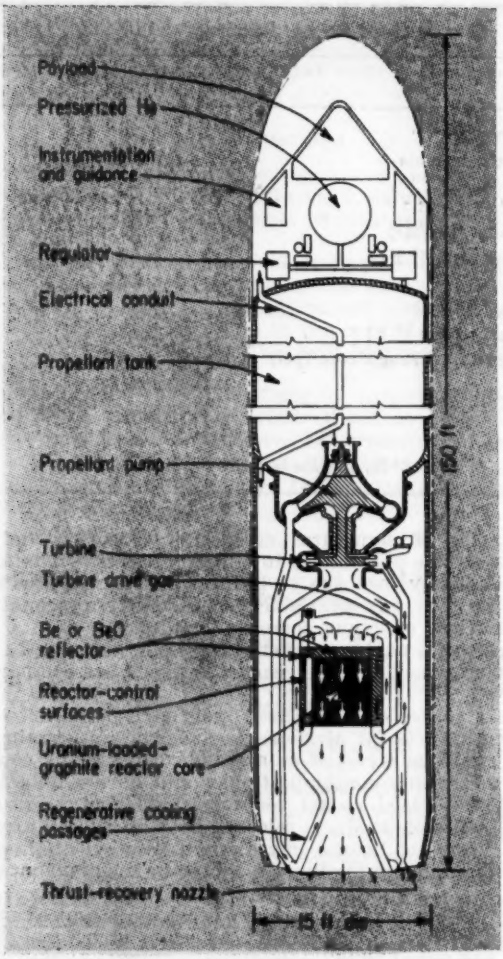
For the first attempt at building a working nuclear rocket, a straightforward solid-fuel-element reactor design (see fig. 1) in which H_2 gas is heated as the propellant (much like the coolant in an ordinary reactor) seems the wisest choice.

Although such a scheme appears unimaginative when compared with other possibilities, it is one that we have confidence that we can build today.

The first step is to decide what available materials have the desired nuclear properties and also have a chance of standing up under the extreme operating conditions of high temperature, high gas flow and high acceleration loads.

If we think in terms of a thermal or epithermal reactor system, then choice of core materials is limited to ceramics such as graphite, BeO, and carbides, which are good moderators, and to a few good moderating metals such as Be.

In terms of high-temperature strength, resistance to H_2, and neutron absorption, graphite seems to be the best of these materials for temperatures of 4,000°–5,000° F. Also, the high-temperature values of the quantity (E is Young's modulus, a is the coefficient of thermal expansion, and k is thermal conductivity Ea/k for graphite are low compared with the other ceramics, which means that lower thermal stresses occur in graphite than in other ceramics.



NUCLEAR ROCKET FLOW SCHEME. Liquid hydrogen is stored in insulated tanks equipped with "blow-off" valves that relieve excessive pressure. Pressurized helium replaces hydrogen as it is drawn off to propellant turbopump. Hydrogen at high pressure ($\sim 10^3$ psia) flows from pump through ducts to exit end of rocket nozzle where it is used to cool nozzle and reactor chamber walls before entering plenum. Most of hydrogen then flows down through reactor and out DeLaval nozzle at 4,000° F. Small amount of hydrogen is diverted at plenum to cool reflector and structural columns. Gas leaving reflector at 1,500° F and 350 psia is used to drive turbine of turbopump. Bypass valve affords turbine control. Turbine exhaust gas is expelled through thrust-recovery auxiliary nozzles (FIG. 1)

In addition, graphite's thermal conductivity is quite good compared with other ceramics, permitting higher exit gas temperatures for a given fuel-element thickness or diameter.

A fast reactor, on the other hand, might appear to be better, since no space is wasted on moderator or reflector. However, the structural-material choice here is even more limited; tungsten is one of the few high-temperature materials available.

Also, for safety, fast-reactor excess reactivity has to be kept less than $1. Since considerable excess reactivity may be needed to compensate losses of core material during operation, a reactor system with enough thermal neutrons to give a reasonable excess reactivity seems like the best approach and is the one we will discuss from here on.

FUEL-ELEMENT DESIGN

Developing a satisfactory fuel element is first on the list of problems. One starts with one of the high-temperature materials, such as graphite, as combination moderator and matrix for the uranium fuel. Then it is necessary to fabricate this mixture into shapes rugged enough to withstand violent thermal and mechanical stresses and yet thin enough to minimize thermal gradients and provide adequate surface area. Some possible fuel element shapes are shown in figure 2. With other things equal, the design with the smallest pressure drop is preferred.

A comparison study of the elements in figure 2 indicates the superiority of sandwich- or plate- type fuel elements and rod-type elements. In this study, all factors were held constant except element shape.

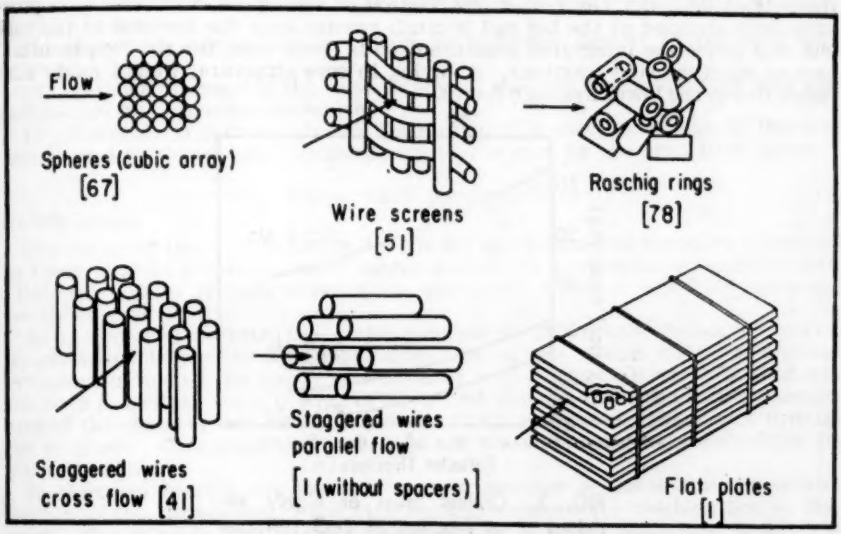


FIG. 2. Possible graphite fuel-element configurations. Studies of relative pressure drop (numbers in brackets) showed flat plates and staggered wires with parallel flow to be superior

Element sizes were determined by temperature and stress limitations. The greater fuel-bundle complexity and greater propellant-flow blockage (with spacers) for rod elements make parallel plate elements the more desirable of the two. The plates could be bound together at several points by drawn tungsten or molybdenum wire.

Conceivably, the elements might be used unclad; alternatively, a ceramic coating could be developed. Plate element thickness is limited on the high side by thermal stress and absolute temperature limits and on the low side by fabrication and rigidity problems. Between 0.030–0.125 inch is a likely thickness range.

CORE DESIGN

Once the decision has been made to use, say, graphite-plate-element bundles, the next problem is to hold the bundles together into a compact, rigid core. The assembly must bear up under a 4,500° F. axial temperature difference, a 1,000-p.s.i. pressure drop, and 10 g accelerations, and at the same time be as small and light as possible. Again, graphite appears to be a good possibility for the structural material.

One possible scheme would use a matrix of lateral beams and cross braces to secure the fuel-element bundles in place. The matrix would transfer the pressure-drop load to metallic tubular tension columns (which are supported from the cold end and run the length of the core) and to the rocket outer wall.

The tension columns would be cooled with liquid hydrogen flowing internally and would be made of a high-temperature metal like molybdenum. The total amount of such material would have to be kept small for a reasonable critical mass. (See fig. 3.)

An alternative all-graphite structure might use a compression arch at the hot end of the core to support the core matrix. This scheme would take full advantage of graphite's superior strength in compression, but would be harder to build than the first one.

An additional worry in laying out the core is that nonuniform coolant-space and fuel-density distributions are required for optimum performance.

For instance, a design using a constant void fraction through the core (void fraction=flow area/total area) would give an almost exponential increase in pressure drop Δp as the gas approaches the hot end of the reactor. A better design would use a variable void fraction through the core to reduce the overall pressure drop across the core, preferably without introducing much additional fabrication difficulty (by proper distribution of void space the decrease in pressure drop attained at the hot end is much greater than the increase at the cold end and hence the integrated pressure drop is lower than for the "exponential" case of constant void fraction). A saving in core structural weight might also result due to the lower dynamic forces.

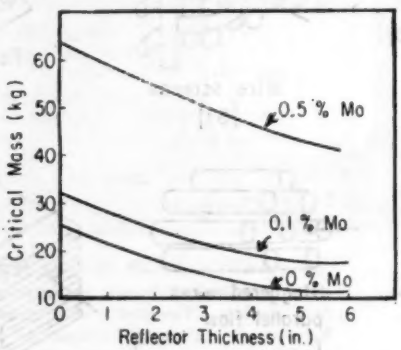


FIG. 3. Critical mass of highly enriched U as function of BeO reflector thickness for epithermal rocket reactor. Three curves refer to different concentrations of molybdenum in U-graphite core 5 ft in diam and 5 ft long

Similarly, to squeeze as much power as possible from the temperature-limited core, the fuel distribution would be varied in both the radial and axial directions to keep the peak-to-average temperature ratio to an absolute minimum.

REACTOR CONTROL

The main function of the reflector would be to act as a variable source of thermal neutrons for reactor control. Figure 3 shows the large reactivity controlled by reflector changes.

For example, the critical mass varies more than a factor of two between the fully reflected reactor and the bare one. By using some scheme of reflector poisoning, this large excess reactivity could be made available for operational needs, which, as we have seen before, may be considerable. Reflector control would also do away with many of the problems of putting control rods in the core of a reactor of this kind and would provide more excess reactivity.

The reflector-poison control elements could be in the form of long boron plates stationed within the reflector around the reactor core and reaching the length of the core. The plates would be rotated in circular slots by a mechanical drive system so that they could be moved from the inner to the outer boundary of the reflector. With the plates turned in, the reflector would send back very few neutrons to the core; with the plates turned all the way out, the maximum number of neutrons would be returned.

During startup, reactor power and fuel flow would be carefully synchronized to establish the final steady-state temperature distribution throughout the core at low power. Power and flow would then be pushed up to their full design values while preserving the temperature distribution.

The first step would be carried out slowly to minimize thermal stresses; the second step must be done as rapidly as possible to conserve propellant. An extremely sensitive and reliable reactor-turbopump control system will be needed to carry out these steps.

During power operation (perhaps sooner) various reactivity changes will occur due to changes in the material composition of the core. Some changes to consider include:

(1) Reactivity change due to change in hydrogen density in the core void volume.

(2) Uniform decrease in the solid volume of the core (including both fuel and moderator) due to corrosion-erosion.

(3) Nonuniform decrease due to destruction of a plate or bundle in the core matrix and its consequent discharge out of the core by the propellant gases.

NONNUCLEAR COMPONENTS

Nozzle design

The design of the ejection nozzle for the hot gas is based on the same principles as those used in chemical-rocket nozzle design. A converging-diverging nozzle (DeLaval nozzle) is used to reach the supersonic exhaust velocities necessary for high thrust.

As in chemical rockets, the major problem in the nozzle design is keeping temperatures below the maximum allowable in the nozzle wall. A common procedure is to cool the nozzle and chamber walls regeneratively. In this case the main propellant (or a portion of it) is first pumped through coolant passages around the chamber and nozzle, after which this preheated fluid is sent through the chamber. Cryogenic hydrogen does not present insuperable difficulties for this application.

In chemical rockets, the greatest heating problem occurs in the converging portion of the throat due to the high velocity-temperature combination at that point. The same is true in the nuclear rocket, with the additional problem of gamma-ray heating from the reactor.

Since the converging section of the nozzle is relatively close to the reactor and since the converging section "sees" the reactor, gamma heating is particularly serious here. Nevertheless, it appears possible to overcome the problem with regenerative cooling.

Chamber design

In the chamber design a very considerable axial force from g-load and drag is transmitted to the shell from the reactor core via the structural support members. This is in addition to the usual hoop stresses due to gas pressure.

A relatively heavy wall is therefore necessary in the chamber. But heavy walls not only decrease overall rocket performance due to greater weight; they also lead to higher wall temperatures and thermal stresses because of heating by leakage gamma rays. (The gas-cooled reflector will help decrease the

gamma-ray intensity to some extent.) As with the nozzle the hydrogen propellant appears to be satisfactory as a coolant for the reactor chamber.

(We gratefully acknowledge the contributions of Mr. John Giovannucci for the reactivity analysis performed utilizing a modified perturbation theory he devised. Mr. Robert Behnke and Mrs. Arlene Pollack performed many of the numerous calculations in the nuclear and engineering analysis which led to the systems described in this paper.)

The CHAIRMAN. Any further questions? If not, we want to thank all of the witnesses who have come here today to help us with these problems that we have.

We will meet tomorrow morning at 10 o'clock. At that time we will take up the electrical propulsion and space problem. We have representatives from the Giannini Cos. of Santa Ana, Calif., representatives from General Electric Co., from the North American Aviation Corp., and from the Lockheed Aircraft at that time.

I think we can handle them all right within the limits of the time.

If there is no further business, the committee will recess until tomorrow morning at 10 o'clock.

(Whereupon, at 12 noon the committee recessed, to reconvene at 10 a.m., Thursday, March 19, 1959.)

SPACE PROPULSION

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., Thursday, March 19, 1959.

The committee met at 10:05 a.m., in room B–214, New House Office Building, the Honorable Overton Brooks, chairman, presiding.

The CHAIRMAN. The meeting will come to order.

This morning we have a number of witnesses. From the Giannini Cos., we have Dr. Gabriel M. Giannini, of Santa Ana, Calif.

Do you have a statement, Doctor?

Dr. GIANNINI. No, sir; not written.

The CHAIRMAN. We have Mr. Fthenakis, manager of navigation and controls engineering, Missile & Space Vehicle Department, General Electric Co., Philadelphia.

Then we have Dr. Robert H. Boden, research specialist, Rocketdyne Division, North American Aviation, from California. We have Dr. Daniel Bershader, manager of Gas & Dynamics Department, Lockheed Missile & Space Division, Lockheed Aircraft Corp., of California.

Finally we have Mr. Y. C. Lee, director of corporate research, Aerojet-General Corp., Azusa, Calif.

We will begin with Dr. Giannini. Doctor, you have no prepared statement, but if you care to, sir, we will be glad to have any informal statement you wish to give us.

STATEMENT OF DR. GABRIEL M. GIANNINI, PRESIDENT, GIANNINI PLASMADYNE CORP., AND TECHNICAL DIRECTOR, G. M. GIANNINI & CO., INC.

Dr. GIANNINI. I will speak a few minutes on electrical propulsion and on why we are here today to discuss nonchemical propellants.

The basic reason for electrical propulsion is to be found in the fact that in conventional rockets the mass which is accelerated within the rocket itself has a limited amount of energy available to it. I will explain this a little more simply by saying that in propulsion through fluids, the only method known to propel a vehicle with any appreciable efficiency is to displace part of the fluid in the neighborhood or within the vehicle and to propel such fluid in a direction opposite to the one in which the vehicle wishes to go.

For example, in a rowboat one just propels some water in a direction opposite to the way the rowboat goes. In an airplane with a propeller one accelerates a mass of air in the direction opposite to the direction of flight.

In a conventional rocket, one accelerates the mass of the propellant in a direction opposite to the desired trajectory.

In order to accelerate this mass which makes the vehicle move, it is necessary to have available a certain amount of energy so as to cause the motion of the mass. In a conventional rocket, the energy which accelerates the mass which is ejected is contained within the chemical itself. Its molecular energy is the energy which is converted into heat. The heat expands the propellant, whether solid or liquid. Once ignited the propellant is in gaseous form and expanding compresses against the walls of the rocket chamber and its potential energy is converted into kinetic energy, the propellant thus being ejected through the nozzle.

The velocity with which this gas is ejected by the nozzle of a rocket depends strictly on the amount of energy which is available in the process. The amount of energy which is available in the conventional rocket is controlled by its source. Its source is chemical energy, that is, the energy which is liberated when the molecules rearrange themselves or when the fuel burns.

This energy, as I said before, is limited. Why is it limited? It is limited because the strength of the chemical bonds is limited. I will make a comparison. When we have a slingshot made out of a rubber band, and a stone, the stronger the rubber band is, the more energy we can transmit into the stone and the faster we can let the stone go.

If we call the rubber band a bond, we find that a chemical bond, that is, a bond that keeps several molecules together, is like a weak rubber band, that is, weaker than the bonds which bind some of the electrons within the atom, or nuclear bonds which bind particles within the nucleus itself. These bonds differ by several orders of magnitude, which means that with chemical propellants we are confronted with slingshots with weak rubber bands which cannot impart too high a velocity to the mass which is ejected. With chemical energy, therefore, we can accelerate large masses of propellant, but at a relatively low velocity.

Therefore, one has been searching for a more effective method of transferring energy into the propelling gas. One way of doing this is electrically. By this means one can translate electron binding energies which are higher than chemical binding energies. These energies are evidenced by and can be expressed in terms of temperature. The maximum temperatures obtainable chemically are of the order of 8,000° Fahrenheit and the only way of converting the heat into kinetic energy is through the use of a nozzle.

Electrically one can go much higher and one can do one or both of two things:

(*a*) Increase the temperature to say, double a value, or

(*b*) Accelerate the gas directly without increasing its temperature, by electromagnetic means.

These are two ways by which we can impart to the gas, whatever material it may originally be, liquid or solid, a greater amount of energy by using electrical means than we can chemically.

The moment we decide to try to reduce this thinking to practice we are confronted with two problems:

(1) One is the source of energy. In a conventional or chemical system, the energy is contained in the propellant itself. In electrical systems such as are being developed today, we must secure an outside source of electric power to drive the propelling mass.

(2) The second problem is to transfer the energy from the source of power into the gas itself, which is to be accelerated.

My colleagues will describe a variety of methods to transfer energy from an electrical source into the acceleration of a gas.

I would like to point out that while I am personally working on one or two of these methods at this time, it is very difficult at this time to predict as to which one of the various approaches will find practical use and for what purpose. We are confronted with a situation similar to that which existed at the time of discovery of gasoline in respect to the future of some particular type of gas engine. One could not have stated in 1900 whether the gasoline engine of greatest acceptance would be a diesel or gas, be 2 cylinders or 16, whether it should be 2 cycles or 4 cycles, whether a piston engine or a turbine.

Similarly each one of the types of electrical propulsion which you will hear about has a particular optimum application to certain particular missions. Some of them are good for satellites orientations, others are good for moving a space vehicle from one orbit to another. Some of them are good only for very long trips and others are good for only relatively small adjustments. There is as much difference between electrical propulsion systems for space vehicles as there is between an outboard motor and the engines in the *Queen Mary* and one cannot be used for the purpose of the other.

The underlying great problem on all of these electrical systems is the power supply. Electric power must be available in light form because otherwise any increase in efficiency which we may obtain in the method of transferring electrical energy into momentum into the gas will be lost in having to carry a heavy weight of electrical equipment.

In other words, an electrical propulsion system in order to be better than a chemical system must have a total weight which compares favorably with it. All of the electrical systems which are being proposed or are being studied have this common problem.

I will wind up my outline by saying that today there seem to be only two types of feasible electrical propulsion systems which are, so to speak, at the opposite ends of the power spectrum.

One utilizes the energy which exists in space in the form of solar energy through solar batteries or thermionic methods. This method is, at this time, limited to very small value of total thrust. It can be used for orienting small missiles, but it is 1 million times too small, for example, to cause a rocket to take off from the ground.

The other source of power is in nuclear fission coupled to conventional electrical generators. With this combination, electric propulsion is, on paper, feasible for large vehicles designed for missions such as a Mars mission.

The greatest need today to make electrical propulsion a success is the development of light power sources in the middle-size range between these two extremes. In this area, while work is being done, there is a long way to go before a practical device becomes a reality. Such a device is essential to give adequate maneuverability to space vehicles.

Thank you.

The CHAIRMAN. Thank you very much, Doctor.

May I ask you this. I have been asking all of the witnesses the same thing. Could you give us some idea of the size of the R. & D. program, research and development program, of your company?

Dr. GIANNINI. I am actually connected with two companies. One is doing about $12 million in production of aircraft instrumentation. One is doing about a million and a half a year in research in this field of electrical propulsion where I have about 100 people.

The CHAIRMAN. The 2 companies, 100 people——

Dr. GIANNINI. I have 1,300 people altogether.

The CHAIRMAN. In this particular work?

Dr. GIANNINI. No. In this particular work, 100.

The CHAIRMAN. I mean in the R. & D. program, research and development program.

Dr. GIANNINI. In one field we are doing instrumentation for missiles and automatic pilots.

The CHAIRMAN. We don't care so long as it is R. & D. work there. We wanted to know just about what the size of your total R. & D. program was.

Dr. GIANNINI. About $3½ million.

The CHAIRMAN. And about 1,200 people?

Dr. GIANNINI. The instrument manufacturing company has 1,200 people and the R. & D. is $2 million, and the electrical propulsion company has 100 people and its R. & D. is about $1½ million.

The CHAIRMAN. Thank you very much, Doctor. We are going ahead and call on the other witnesses because the House convenes at eleven this morning. These people have come from long distances. We want to hear them all, and all of the time we have remaining we will use for questioning them.

Next we have Mr. Emanuel Fthenakis, manager of navigation and controls engineering, Missile and Space Vehicle Department, of General Electric.

Mr. Fthenakis.

STATEMENT OF EMANUEL FTHENAKIS, MANAGER, NAVIGATION AND CONTROLS ENGINEERING, MISSILE AND SPACE VEHICLE DEPARTMENT, GENERAL ELECTRIC CO.

Mr. FTHENAKIS. I do not have a prepared statement. I will try to say a few words here. My main object would be to cover the area of electrical power which is one of the basic problems in these electrical propulsion systems.

Of course in the space applications the electrical power is not only used for the propulsion but other functions. I have here a chart which indicates the factors that have to be considered in the design of power supplies. These are the propulsion, the navigation elements—that is, the sensing, computing, and actuations—plus the payload requirements, such as a warhead or instrumentation package, life support or any other payload packages that exist in the vehicle.

I am about to show you a few numbers which by no means are 100 percent accurate. They indicate how the electrical power divides among the above functions.

I would like to emphasize that these are already published elsewhere and contain no classified information. Therefore, it is not the latest that could be said. They just give an order of magnitude.

(The first chart is as follows:)

USE OF ELECTRICAL POWER

A. PROPULSION
- -ION PROPULSION
- -PLASMA JET ACCELERATORS
- -MAGNETOHYDRODYNAMICS
- -OTHERS

B. NAVIGATION AND CONTROL
- -SENSING
- -COMPUTING
- -ACTUATING

C. PAYLOAD
- -WARHEAD
- -INSTRUMENTATION
- -LIFE SUPPORT
- - OTHER

Mr. FULTON. Why don't you have thermodynamics on the chart?

Mr. FTHENAKIS. In this area?

Mr. FULTON. Any place at all before you leave the chart.

Mr. FTHENAKIS. Thermodynamics? I am here indicating the areas we use electrical power.

Mr. FULTON. Couldn't you have thermodynamics under that A propulsion, changing heat into electricity?

Mr. FTHENAKIS. Right. This will be the power supply. I am going to go into that. The way by which you obtain the electrical power.

Mr. FULTON. I just wondered why you had left it out of the chart.

Mr. FTHENAKIS. Because the thermodynamics as such is not a unit. It is just a principle. It is not a unit that you have to supply with electrical power.

Mr. FULTON. Go ahead.

Mr. FTHENAKIS. I indicate here numbers of our anticipated requirements in the propulsion area. Over here I have the type of propulsion like ion propulsion, plasma, chemical rockets, nuclear, and photon. This is like solar cells.

(The table referred to is as follows:)

Anticipated requirements: A. Propulsion

Type of propulsion	Thrust (lbs.) or specific impulse (sec.)	Electric power kw./lb. thrust	Voltage, kv.
Ion	0.1–2.0 (lbs.)	200–300	10–25.
Plasma	0.5–2.5 (lbs.)	200–300	10–25.
Chemical rockets	1 (lb.) to 5×10^6 (lbs.)	1–300 w. (squib only)	6–30 v. (squib only).
Nuclear	700–2,000 (secs.)		
Photon (solar sails)	10^7–10^8 (secs.)		

Mr. FTHENAKIS. I have here a typical number of the pounds of thrust you can get out of that, or the impulse in the case of the chemicals.

Over here you see that we have two-tenths of a pound in the ion propulsion, which is contrasted with the millions of pounds we are talking about in the chemical rockets.

Over here I have the electrical power that is required—i.e., kilowatts for each pound of thrust that we get out of these devices. I think this is indicative of the size of the electrical power requirements. I have over here, just for comparison purposes, the electrical power in ordinary consumption. I took Philadelphia—it is around 600,000 kilowatts, and 10,000 population city with an average use per residence of about 0.4 kilowatt.

(The table referred to is as follows:)

Average electric power consumption

	Kilowatts
Philadelphia	622, 569
U.S. residential city (10,000 population)	970
Average U.S. residence	.4
Iowa-class battleship	100, 000

Mr. FTHENAKIS. You have here the *Iowa*-class battleship, which is about a hundred thousand kilowatts.

Mr. WOLF. I am awfully glad to have you mention the word "Iowa."

Mr. FULTON. May I comment favorably on Philadelphia, too?

The CHAIRMAN. I will comment on the battleship. In that ion-type propulsion you would have twice as much as in a battleship?

Mr. FTHENAKIS. As I said, the battleship has a powerplant of about 100,000 kilowatts to provide all the needs. An ion propulsion device needs about—this is a typical number—250 to 300 kilowatts per pound of thrust. I say "per pound of thrust." I am not talking about millions of pounds which we are talking about in the chemical case.

Mr. FULTON. May we put these charts in the record at this point?

The CHAIRMAN. Yes; the charts will be in the record. Do you have available——

Mr. FTHENAKIS. I can leave these charts.

I have here the other requirements besides propulsion with mission type that have to supply the payloads. This is the weapon type like a ballistic missile or reentry vehicle. This is in watts, minimum or maximum.

(The table referred to is as follows:)

B. Future total power requirements, 1959–70

Mission type	Power (watts) requirements		Feasible hardware
	Minimum	Maximum	
I. Weapons:			
Ballistic missile (reentry vehicle only):			
R. & D.	500	2,000	A. Silver zinc batteries.
Operation	15	500	B. Fuel cells.
			C. Isotope—thermionic converter.
			D. Solar converters.
Short range:			
R. & D.	300	2,500	A. Silver zinc batteries.
Operations	50	1,500	B. Turbine generators.
II. Satellites:			
Communications	20	5–10,000	A. Silver zinc battery (minimum power and up to 48 hours only).
Reconnaissance	30	5,000	
Man in space (1 man)	500	800	B. Fuel cells.
Man in space (2–5 men)	800	5–10,000	C. Isotope or solar thermionic converter.
Scientific probe (such as mapping magnetic fields, radiation field, etc.)	25	6,000	D. Solar converters.
			E. Nuclear—turbine generators (high), power>10kw.
Space station	2,000	[1] 1,000	
III. Interplanetary:			
Moon:			
Unmanned	10	2,000 (10–15 kw. [2])	A. Silver zinc batteries.
Manned	500	2,000 (15–20 kw. [2])	B. Isotope or solar thermionic converter.
Venus:			
Unmanned	200	2,500 (20–30 kw. [2])	C. Solar converters.
Manned	700	3,000 (50–60 kw. [2])	D. Fuel cells.
Mars:			
Unmanned	200	2,500 (20–30 kw. [2])	E. Nuclear turbine generator.
Manned	700	3,000 (50–60 kw. [2])	

[1] Kilowatts.
[2] If ion propulsion is used.

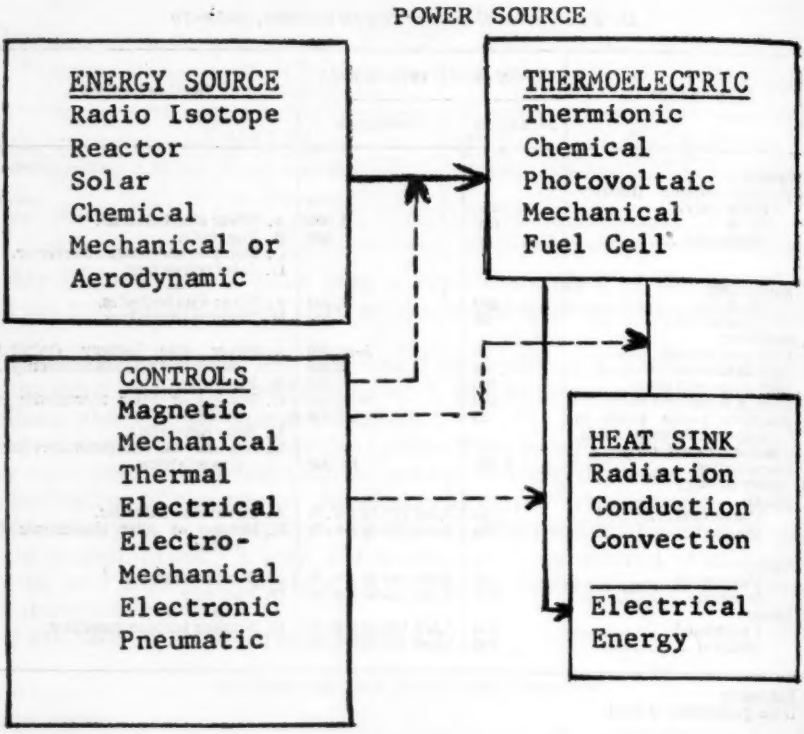
Mr. FTHENAKIS. This is just an order of magnitude. It can vary, depending on the missile. This is the kind of power supply which I will go into in more detail a little later, which could supply that kind of power.

We have a second kind of mission here, which is a satellite mission, like communications satellite, reconnaissance, one man in space, two men in space—scientific probes, or space stations—which ends up to the thousands of kilowatts up there—just indicating what are the requirements you anticipate in a case like this.

Over here I have the requirements in power you anticipate in the interplanetary missions. I have selected three—the Moon, Venus, and Mars—unmanned and manned. In all three of them—I have indicated with these low figures in parentheses the cases where you need ion propulsion or plasma jet accelerators, or electrical propulsion. The rest of the power is used for the payload.

This is as far as the requirements for power go. Now we try to get very light and cheap power in high altitudes. So I will indicate the methods that today are being investigated. Of course in getting electrical power, you have to have a basic energy source. Here I have the energy source that you can use—radio isotope, nuclear reactor, solar energy, chemical, mechanical, or aerodynamic—really I am talking about the aerodynamic principle.

(The diagram referred to is as follows:)



Mr. FTHENAKIS. Of course this is the heat energy, and you have to convert to electricity. You have to have a conversion device. I am indicating here the number of conversion devices like thermoelectric, thermionic. Thermoelectric uses the difference of potential between two metals at different temperatures. Thermionic is boiling the electrons out of a metal. Heat it up and boil the electrons, collect them and so obtain a current flowing from cathode to anode.

This is a thermionic button. There are dozens like this. I got it out of the research laboratory. This is about a quarter of a watt thermionic button. [Passes around exhibit.]

Photovoltaic: That is the ordinary solar cell that converts to electrical energy. Mechanical: Like a turbine or reciprocating turbine or a generator; and fuel cell, which is required chemically, really energy.

This is a reverse process like a battery process.

I have over here a fuel cell to indicate to you what the thing looks like.

The CHAIRMAN. Could you let us pass it around?

Mr. FTHENAKIS. Yes, I will. Of course you need, besides that, the secondary equipment to go with the power supply. This is not 100 percent efficient. Actually it is only 5 to 10 percent efficient.

Then the rest of the thermal energy has to be dissipated in some way so you don't burn up your devices. You have to have heat sinks

or radiation shielding in the case of nuclear energy. Actually this is one of the disadvantages of nuclear energy.

While you can have very light equipment if you had personnel working next to it, you have to have a tremendous amount of shielding. The same is true for any electronic equipment next to it. And this is the controls you need to regulate that power, that is, the rate at which it is produced.

The state of the art in this particular power source, the power supplies today, is that there are power-supply prototypes built that prove very well the feasibility. To my knowledge I have not seen a flyable unit, a unit that could really be put into a missile and go up in this category.

(The final table is as follows:)

State of development

Power ratings	Development time	Approximate weight (pounds)
1 kilowatt	6 to 20 months	60
3 kilowatts	About 20 months	150
30 kilowatts	36 months	1,000
1 megawatt	5 years	5,000

NOTE.—Provided a very intense effort is made.

Mr. FTHENAKIS. I will be glad to answer any questions later on, on this subject.

The CHAIRMAN. Thank you very much, sir. We appreciate your explanation. It will help if we can put your chart in the record.

Mr. FULTON. I have one question on your controls. Do you have in there command controls from the ground?

Mr. FTHENAKIS. These controls over here——

Mr. FULTON. They all seem to be inertia controlled. Do you include there command controls from the ground?

Mr. FTHENAKIS. These are controls that control the rate, are self-contained. They control the rate by which you release the energy.

Mr. FULTON. We have command control from the ground, too, or from other stations. Are you considering that?

Mr. FTHENAKIS. This is not the type of controls I am considering here. This is, for example——

Mr. FULTON. That is all I need; thank you.

The CHAIRMAN. Thank you, sir. We have Dr. Robert H. Roden, and he is research specialist, Rocketdyne Division, North American Aviation Corp. But Mr. Thomas E. Dixon, chief engineer for the same company, I understand will do the talking.

Mr. DIXON. That is correct, sir.

The CHAIRMAN. We have a prepared statement, too, I believe by you, Mr. Dixon.

STATEMENT OF THOMAS F. DIXON, CHIEF ENGINEER, ROCKETDYNE DIVISION, NORTH AMERICAN AVIATION, INC.; ACCOMPANIED BY DR. ROBERT H. BODEN, RESEARCH SPECIALIST, ROCKETDYNE DIVISION, NORTH AMERICAN AVIATION, INC.

Mr. DIXON. Mr. Chairman, we have a prepared statement here.

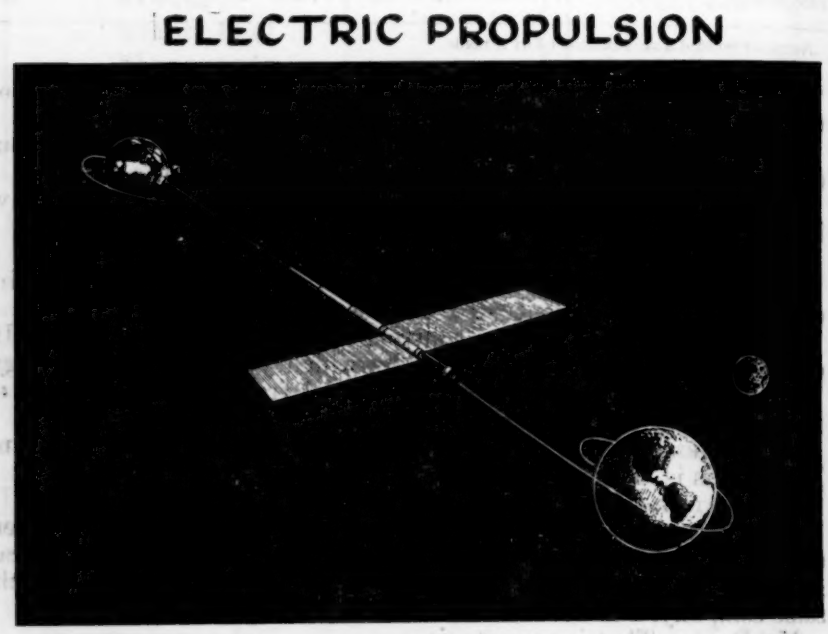
The CHAIRMAN. I think everybody here has copies of them, haven't we?

Mr. DIXON. In accordance with the committee's request we have prepared a short statement covering the characteristics of the electrical propulsion engine.

The rapid advances in electronics, mechanical and electrical engineering, physics, and space technology are leading to unique types of powerplants which give us increasing capabilities for space travel. Previous discussion with your committee has summarized the chemical and nuclear rockets. This discussion covers electrical powerplants, and particularly the ion rocket engine.

Chart 1 is an artist's concept of an electrically powered vehicle which has been proposed.

CHART NO. 1



Mr. DIXON. This concept is satisfactory for interplanetary missions. Before discussing it in detail, however, electrical propulsion systems and their capabilities will be surveyed.

The ion rocket engine is a high-impulse, low-thrust device. It is not capable of boosting a vehicle from the ground. Once space borne, a vehicle powered with an ion engine can carry large loads for substantially longer periods of time than can chemical and nuclear powerplants. Because of the mutually dependent relationship of the

ion and conventional rocket vehicles, it is apparent that the ion engine supplements the chemical and nuclear rocket engines. A balanced development program will include the three engine types.

Within the next 5 to 10 years the three engine types will be in operation for space propulsion. Chart 2 summarizes the high points of the discussion on the chemical and nuclear rocket engines and presents comparable data on the ion engine.

CHART 2

Engine type comparison

Type	Chemical	Nuclear	Electrical (ion)
Thrust	6,000,000 pounds	1-4,000,000 pounds	1-10 pounds.
Performance	400+	800-1,200	5,000-50,000.
Thrust/weight	100	30	1/5,000.
APPLICATIONS			
1-5 years	Booster upper stage space.		
5-10 years	Booster	Booster and upper stages.	Upper stages and space

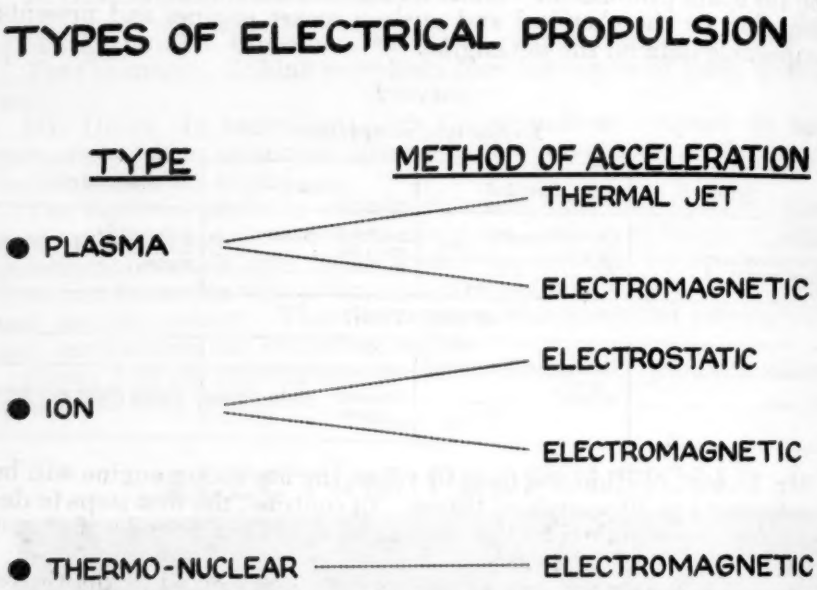
Mr. DIXON. Within the next 10 years, the ion rocket engine will be developing 1 to 10 pounds of thrust. In contrast, the first steps to develop booster chemical rocket engines of 6 million pounds of thrust are underway.

The relative performance of the engines is presented in the thrust generated by each engine for a fuel flow of 1 pound per second. On this basis the chemical rocket generates 400 pounds of thrust, the nuclear rocket 800 to 1,200 pounds, and the electrical rocket between 5,000 and 50,000 pounds of thrust for 1 pound of propellant burned in the given unit of time—1 second. This is the characteristic which permits electrical powerplants to accomplish missions beyond the scope of chemical and nuclear engines.

The third comparison factor is the ratio of thrust produced to weight of the engine. Chemical and nuclear rockets produce high thrusts per unit weight, making these engines ideal for booster and soft-landing applications. Electrical and ion powerplants produce low thrust per unit of weight. Therefore, the ion engine must have boost assistance of the other types, but once in space it can become effective as a propulsion system. On short missions, the high-thrust rocket reaches its destination more quickly. As the mission duration increases, the time penalty of the electrical propulsion system diminishes steadily until it vanishes.

The types of electrical propulsion systems which have been analyzed at Rocketdyne include plasma, ion, and thermonuclear engines, chart 3.

CHART NO. 3



Mr. DIXON. Two types of plasma engines are known, the thermal jet and the electromagnetic accelerator type. In the thermal jet, the propellants are vaporized and heated electrically to a temperature and state comparable to or higher than those achieved in conventional rocket engines. Thrust is then generated by the expansion of the hot gases through a nozzle in precisely the same manner as conventional rocket engines.

The plasma temperatures rapidly exceed the capabilities of currently known materials to withstand these very high temperatures. This problem is solved by using electromagnetic fields to contain and accelerate the plasma, an intimate mixture of ions, electrons, and neutral particles. Extensive analyses show that an operating space engine can be realized in a relatively short period of time by using well-known scientific techniques. If the ions and electrons are first extracted from the plasma and then accelerated in separate jets to develop thrust, this type of rocket engine is the ion engine. If the ions are accelerated by electrical fields only, the unit is called an electrostatic ion engine. If the jet is generated by the combined action of electrical and magnetic fields, the engine is called an electromagnetic ion engine.

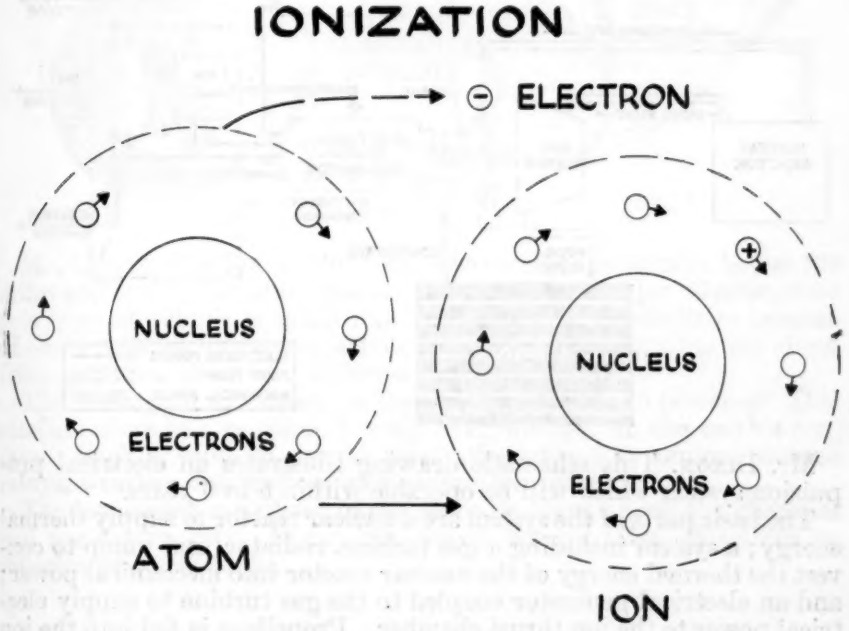
The ultimate rocket powerplant will probably be developed from the application of thermonuclear processes for power, plasma, and electromagnetic field generation. Technical feasibility of these processes has not been proven at this time. It is known that the thermonuclear process is capable of generating enormous amounts of power from minute amounts of fuel. Therefore, developments in this field are being followed with intense interest. The thermonuclear process

will result in complete ionization of the propellant. Acceleration of the jet will be obtained by induced or external, electromagnetic fields.

This discussion has thus far been concerned with ions, electrons, plasmas, etc. It is appropriate at this point to clarify these ideas and to determine how they influence the propulsion picture.

According to modern concepts, a substance such as a metal is an array of atoms, or molecules, held in a regular pattern, called the space lattice, by interatomic forces. As energy is poured into the substance by heating or electrical processes, the interatomic forces are overcome and the substance passes first into a liquid, then the vapor state. The atoms consist of a nucleus surrounded by a dynamic array of electrons (chart 4).

CHART NO. 4



Mr. DIXON. The nucleus is a complex entity of protons, neutrons, and electrons. The nucleus has most of the mass of the atom. The lightest nucleus is that of hydrogen, a single proton, which is approximately 1,840 times the weight of an electron, and of equal and opposite charge. When energy is poured into the atom, one or more of the dynamic electrons surrounding the nucleus can be separated from the nucleus. When this occurs, the process is known as ionization. The nucleus and its remaining electrons carry a charge equal and opposite to that of the electrons removed, and are called an ion. Since the lightest ion is 1,840 times the weight of the electron, ions are of primary interest for propulsive purposes.

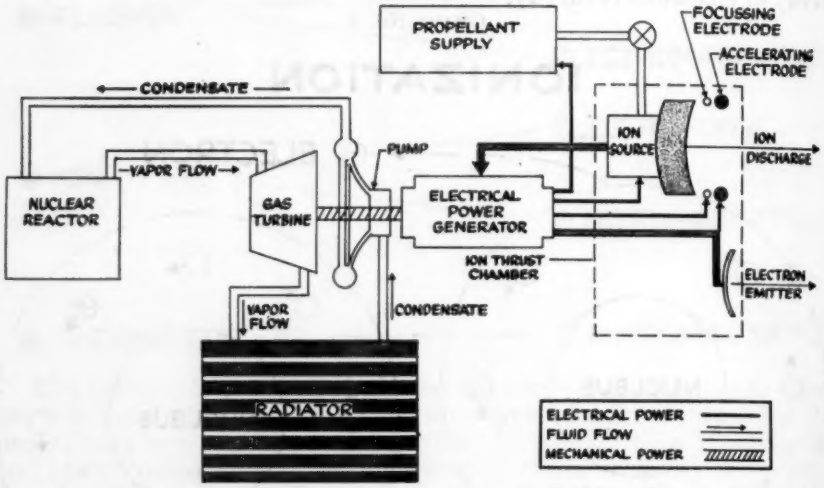
When ionization occurs in a gas, the resulting cloud of atoms, ions, and electrons is known as a plasma. If there are no atoms left, and only ions and electrons are present, the cloud is an ideal

plasma. While thrust can be developed by direct ejection of plasma, practice has found it better to separate ions and electrons, accelerate them individually, and finally to allow them to remix in outer space.

Mechanisms for generating a plasma, separating the ions and electrons, then separately accelerating them into a high-velocity jetstream are included in the various components of the electrostatic ion rocket engine (chart 5).

CHART No. 5

TYPICAL ION PROPULSION SYSTEM SCHEMATIC



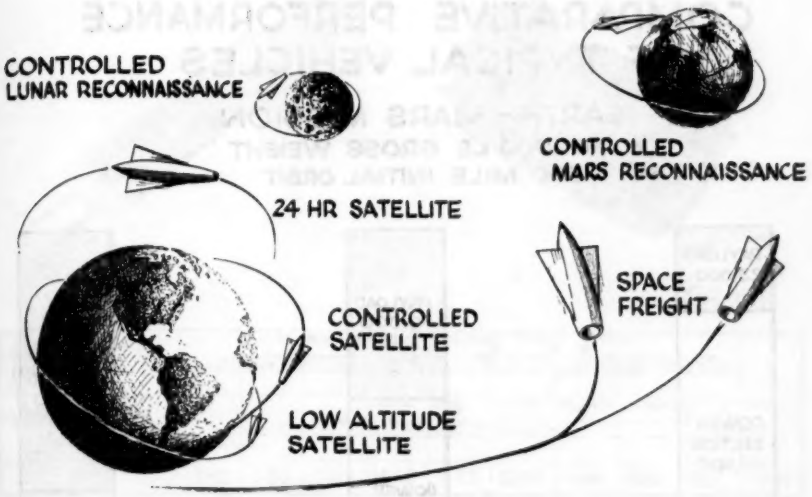
Mr. DIXON. This schematic drawing illustrates an electrical propulsion system which will be operable within 5 to 6 years.

The basic parts of the system are a nuclear reactor to supply thermal energy; a system including a gas turbine, radiator, and pump to convert the thermal energy of the nuclear reactor into mechanical power; and an electrical generator coupled to the gas turbine to supply electrical power to the ion thrust chamber. Propellant is fed into the ion source as a gas. Here the plasma is generated and the ions and electrons are extracted from the plasma mixture. The ions are accelerated immediately into a high-velocity jet which produces most of the thrust. The electrons are collected at the source and then flow through the generator, and to an electron emitter. Here the electrons are ejected at a rate to balance the ion jet.

This ion engine can be incorporated in a rocket vehicle which can be effectively combined with a chemical or nuclear rocket. The high-thrust rocket boosts the ion rocket into an initial orbit from which it can take off on many missions. These missions are summarized in chart 6.

CHART NO. 6

ION ENGINE APPLICATIONS



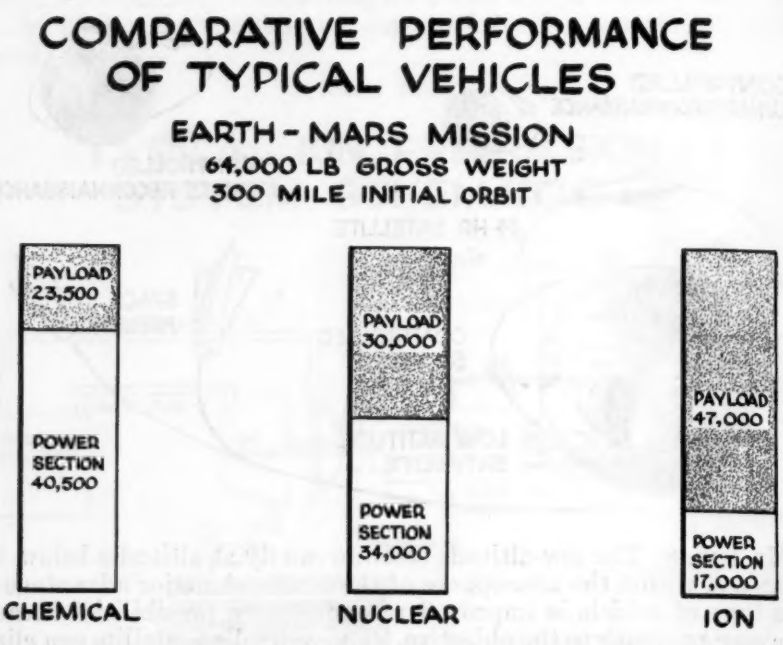
Mr. DIXON. The low-altitude satellite can fly at altitudes below 100 miles and within the atmosphere of the earth. A major advantage of this type of vehicle is improved reconnaissance possibilities because of closer approach to the objective. The controlled satellite can climb from an initial orbit to a different orbit and return.

The ion engine will maintain the 24-hour satellite in position. This satellite stays in a position directly over one spot on the earth's surface. Such a satellite can be used effectively for communications relays, weather observation, and navigation references.

The ion engine can travel to the Moon or Mars, as can the chemical and nuclear rockets. It can also travel beyond these objectives on interplanetary missions.

The ion rocket vehicle is effective as a space freighter, an effectiveness demonstrated by the comparative performance of chemical, nuclear, and ion vehicles, which are summarized in chart 7.

CHART NO. 7



Mr. DIXON. The freight vehicle, weighing 64,000 pounds total, is initially boosted to a 300-mile orbit by a chemical or nuclear rocket. It takes off for its mission to the Moon, Mars, or Venus from this orbit. If chemically powered, it will deliver a 23,500-pound payload. A nuclear rocket will deliver 30,000 pounds, and the ion vehicle 47,000 pounds. The flight times for the chemical and nuclear rocket are approximately the same.

For the Mars mission, the ion rocket would require 350 days' flight time. In contrast, the chemical or nuclear rockets place their lighter payloads in orbit about Mars in approximately 260 days.

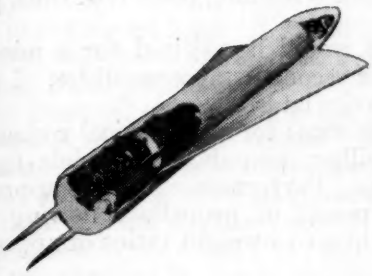
A Mars reconnaissance vehicle has been suggested to various agencies. This has been called the Snooper project. The vehicle proposed is illustrated in chart 8. (Same as chart 1, p. 192.)

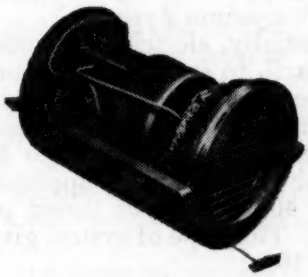
The nuclear powerplant and rocket engines are in the aftersection which carries large wrap-around, winglike radiators. The reconnaissance instrumentation is in a section forward of the small winglike appendages. These supply cooling to the instruments.

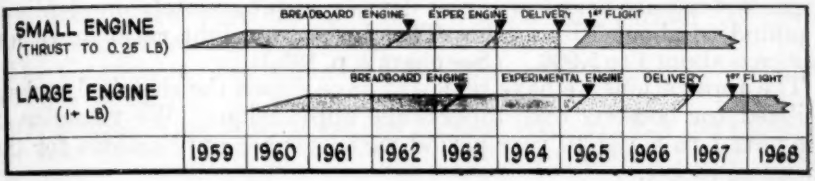
Another vehicle concept and a photograph of an ion rocket engine model, which is the objective of research projects now being conducted at Rocketdyne, are shown in chart 9.

CHART NO. 9

ION ENGINE PROGRAM







Mr. DIXON. A rocket thrust chamber similar to this model will be developed and the flight test engine ready for test in 5 years. An engine of higher thrust will follow in another 1 to 2 years. The development schedule is shown in chart 9.

The results of studies performed during the past several years clearly indicate that the ion rocket engine is a promising thrust-generating device for application to outer space vehicles. Its successful development will be accomplished within 5 to 6 years.

Immediate applications for this rocket engine result from the current developments of high-thrust booster engines. These applications include low-altitude satellites, the stationary satellite in 24-hour orbit, and controlled satellites.

(The summary chart is as follows:)

SUMMARY

Ion engine technically feasible.
Successful development can be completed in 5–6 years.
Immediate applications are: Low-altitude satellite, orbital control, stationary satellite.

Mr. DIXON. We would like to summarize our statement by charts, if permissible.

The CHAIRMAN. Surely. You do just as you wish, Mr. Dixon.

Mr. DIXON. You have heard in the last several days discussions on the chemical rockets, the nuclear rocket, and this morning we would like to discuss the characteristics and applications of the electrical propulsion devices.

On the chart is depicted a typical electrical propulsion device in space. This is a type of device that has a very low thrust. It is quite heavy. It requires that it be brought into orbit by the chemical or nuclear rocket. (See chart 1, p. 192.)

It is a type of device that will operate for long periods of time, perhaps for a year or 2 years.

Essentially, electrical propulsion would be utilized for a mission from earth to another planet or for reconnaissance satellites. I will describe the characteristics of this device later.

Let me offer the following comparisons: for the chemical rocket we visualize thrust levels up to 6 million pounds, the vehicle to be used for various booster applications. Performances will be approximately 400 pounds of thrust per pound of propellant flowing per second. This type of system gives thrust-to-weight ratios of approximately 100.

The nuclear rocket will have a thrust-to-weight ratio of approximately 30, and impulses ranging from 800 to 1,200 seconds. The electrical systems are very low thrust devices, approximately one-tenth of a pound to about 10 pounds. The thrust-to-weight ratio in an ion device is about 1 to 5,000. (See chart 2, p. 193.)

The applications we have reviewed have shown the chemical rockets utilized for boosters and upper-stage applications. We visualize in the next 1 to 5 and 10 year period various space applications for the chemical rocket.

The nuclear rocket as discussed yesterday showed very excellent advantages for large boosters and also upper-stage devices. The electrical system may be likened to a freight train. It is a low pusher, but it will push on the payload for a long period of time. Over a 1-year period, the original velocity of 2,500 feet a second can be increased up to 100,000 feet a second.

Thus, the electrical system is applicable to upper stages and also for space vehicles.

Let me summarize the three major types encountered in electrical propulsion: the plasma type, the ion, and the thermonuclear. (See chart 3, p. 194.)

The plasma type is essentially one for accelerating a mixture of gas or matter that has been electrically heated or ionized to a very high temperature. This gas can be expanded in two ways. One is by the thermal means, because it is at high temperature. The other method is through electromagnetic means. In the latter the gas is ionized. It has an electrical charge and can be accelerated to very high velocities.

The ion system also involves charged particles. There are two ways of accelerating them, electrostatic or electromagnetic, depending upon the type of device available.

The greatest energy available from electrical propulsion is thermonuclear. This is essentially a fusion-type device with controlled reaction that takes place very similar to that in a hydrogen bomb. Minimum temperatures are reached which are very close to those of the sun.

At these temperatures, matter is in the ionized state. Since it is ionized, the matter can be accelerated at very high velocities through electromagnetic means. This type of device is in the early research phase and not very much is known about it today.

Mr. FULTON. Who is doing that research work, please? Can you put that in the record?

Mr. DIXON. The program that is looking toward this particular area is Project Sherwood under the Atomic Energy Commission.

Mr. FULTON. What companies are working on it? You can put that in the record later. I would like an amplification of that.

(The material requested is available in regular reports of the Atomic Energy Commission.)

Mr. DIXON. Let us examine the concept of ionization. Mr. Fulton mentioned such fuels as cesium. Cesium is a type of fuel that has an excellent application in ion propulsion. Essentially this is a central atom. It consists, as we all know, of a nucleus which contains protons and neutrons and electrons ranged in a lattice-type structure around the nucleus. (See chart 4, p. 195.)

If you electrically charge this atom, you begin to activate it to the point where one or more of these electrons leave. When they leave the atom becomes charged and we call it an ion. That is essentially what takes place when we use these fuels that Mr. Fulton has mentioned such as cesium.

The CHAIRMAN. You mean an atom minus the electrons—some of them—is an ion?

Mr. DIXON. That is what we call an ion; yes, sir. Let me explain a nuclear rocket. This is a schematic of such a device. (See chart 5, p. 196.)

Mr. FULTON. May I comment there. An atom giving off electrons is ionized.

Mr. DIXON. That is correct.

The CHAIRMAN. You wouldn't say it the other way? You wouldn't say it is an ion?

Mr. DIXON. We call it an ion, but I think Mr. Fulton is correct in his terminology.

The ion propulsion system consists of electrical power as mentioned before; a propellant such as cesium; and an ion thrust chamber. The electrical power system supplies the electrical energy which is used for ionizing the propellant and accelerating it.

A type of device for operation in space must be self-contained. It must have energy. The nuclear reactor depicted on the chart provides heat to some fluid that will flow through a turbine at high temperatures through an expansion cycle like a steam turbine. The heat exchanger on the missile actually dissipates heat by radiation. It will cool the material to the point that it is in liquid state again.

The fluid is then pumped back through the reactor, where it is heated again in the vapor state and expanded through the turbine. Essentially this is a continuous power source for driving an electrical power generator.

This generator supplies power to the ion propulsion system. Essentially we apply electrical energy to the propellant, focus the ion beam and accelerate it at very high velocity.

Exhaust velocities can be up at levels of half a million feet per second.

Now the problem for the engineers is to package these components in a very lightweight device.

The CHAIRMAN. How are they making out with that?

Mr. DIXON. I will tell you about some of the designs we have. I believe I can answer your question. The applications we see for such——

Mr. FULTON. Would you hold on for just a moment. A half a million feet a second is 100 miles a second, and that is 360,000 miles an hour, isn't it?

Mr. DIXON. Yes.

Mr. FULTON. That is 3,600 times 100, which is 3,600,000 miles an hour, which is what you are talking about, isn't it?

Dr. BODEN. That is correct, Mr. Fulton.

Mr. FULTON. 3,600,000 miles an hour you are accelerating these particles to?

Dr. BODEN. Yes; half a million feet per second is from a lower limit. We are looking at velocities up to 1 million and as high as 5 or 10 million feet per second.

Mr. FULTON. Are you working, as the Russians have been, about the speed of light or exceeding it?

Dr. BODEN. No, sir, we are not. We do not think this can be achieved, certainly within any reasonable time.

Mr. FULTON. You then disbelieve the Russians' statement that they have already accelerated particles beyond the speed of light?

Dr. BODEN. I did not say that, sir. I said we as a company are not looking at particles traveling at the speed of light. We do not feel that particles traveling at the speed of light can be effectively applied as thrust generators. Too much power is required for this purpose. We cannot build a vehicle with that much power in it.

Mr. FULTON. Thank you.

The CHAIRMAN. Proceed, sir.

Mr. DIXON. I will leave this ion engine model for your inspection. If you have any questions, Dr. Boden will describe it to you.

The CHAIRMAN. Dr. Sheldon can pass the model around.

Mr. DIXON. This represents around a quarter of a pound thrust actual-size ion propulsion device. This portion is the ion thrust chamber of the engine.

The CHAIRMAN. That buzzer is an indication that Congress is going to convene in 15 minutes. We are going to run as long as we can this morning, but there are some rollcalls today which we have to make. So go ahead and proceed as rapidly as you can conveniently.

Mr. DIXON. The applications of the ion propulsion are several. One of the major applications is in satellite type control. One such envisions a low-altitude satellite approximately 65 miles above the earth's surface. We would like to maintain the satellite in such an orbit for long periods of time. Utilizing the small push of an ion rocket, it can be kept at that particular altitude. As you know, at an altitude of approximately 65 miles (unless you have some propulsion device) the satellite will eventually return to the earth's surface. So, for such low-altitude areas of reconnaissance, this device would be very attractive. (See chart 6, p. 197.)

A satellite must be controlled when moved from one orbit to another. This propulsion device has very good applications in that area. A 24-hour satellite, as you know, moves with the surface of the earth. To keep it in one spot or to move it from one spot to another a propulsion device could be used.

Then of course some of the future applications are for space freighters, moving from the earth's orbit to, say, Mars or Venus or other planets. It is a slow device in the trip from here to Mars, which we visualize as around 350 days' travel time. Then of course, applications around the moon are possible.

The major applications in the early phases would be for satellite applications. Later phases could be for use in space.

The CHAIRMAN. How far away is that type of engine?

Mr. DIXON. I will tell you, sir.

Mr. FULTON. What is the limit of acceleration on an ion engine?

Mr. DIXON. Your question: The ion engine, we believe, can be available in about 5 to 6 years.

The CHAIRMAN. Now, Mr. Fulton's question.

Mr. FULTON. What is the limit on your acceleration speed using the ion engine?

Mr. DIXON. We visualize that the optimum designs of our studies that we have had as around 10^{-4} g, which seems to be about the optimum from the point of view of accelerating a payload in space.

A comparison is depicted on the chart. (See chart 7, p. 198.) The mission is from an earth orbit of 300 miles to Mars. This is a space-freight-type mission, a slow operation lasting about a year.

The ion rocket in this case gave us a higher payload for this space-freight operation. Certain other type missions which we discussed yesterday would show that the nuclear rocket looks better than the ion, but in this case, for specific missions, the ion is very attractive, in terms of allowing a larger payload in space, over the other chemical, and nuclear propulsion, devices.

This chart is essentially the picture you saw before, a device we call Project Snooper. (See chart 1, p. 192.) It is a proposed program essentially for reconnaissance around another planet such as Mars. Such an ion missile here would be propelled chemically to an orbit about the earth. From there it would take off, say, toward Mars or another planet.

This device is about the same size as this model here, around a quarter of a pound thrust. The whole device, including the electrical equipment, the nuclear power, would weigh around 4,000 pounds. The propulsion part, including the electrical, would be about 1,100 pounds. (See chart 9, p. 199.)

The remaining section can be part of the structure and the payload. It might be instrumented to take certain photographs and data over Mars to determine what the planet characteristics are. Here is an example of one type of device that we could see for space application.

The CHAIRMAN. Is that device coming or going?

Mr. DIXON. This is going, sir. You can see here we have the ion exhaust jet. I did not mention that we must keep this whole device electrically neutral. So we eject the electrons. Electrons have very little mass—in fact, almost none. But we eject that.

At some point out in space they meet and are neutralized. That is the reason you see two jets.

The equipment is located forward. This is the radiation heat exchanger. These are all essential—they are not wings. We call them radiation devices, radiators out in space that radiate heat to space and cool the electrical equipment and the working fluid of the

heat exchanger. In this case the equipment is in the forward compartment.

In terms of a schedule of such an ion program, we visualize a quarter of a pound thrust device in about 5 to 6 years. If there are larger requirements, for about 1 pound, we visualize development a couple of years later. (See summary chart, p. 199.)

Mr. FULTON. When you said the practical acceleration of the ion engine, did I understand 10^{-4} g.? That would be 0.0000315. Is that what you are speaking of?

Dr. BODEN. No, sir. It would be 0.0001. You might look at it this way. If you have a 10,000-pound thrust vehicle that weighs 10,000 pounds——

Mr. FULTON. 10^{-4} g.

Dr. BODEN. That would be 1 pound of thrust in a 10,000-pound vehicle; a quarter of a pound of thrust in a 2,500-pound vehicle.

Mr. FULTON. Say that again?

Dr. BODEN. Your 10^{-4} g is 0.0001. That is 1 pound of thrust in a 10,000-pound vehicle. A quarter of a pound of thrust in a 2,500-pound vehicle.

Mr. FULTON. Mathematically speaking, if you take 10^{-4} g, whatever figure you get multiplied by the factor 0.0000315. Isn't that it?

Dr. BODEN. No. It is 0.0001. It is the ratio of the thrust to weight.

Mr. FULTON. It is the ratio, not the 31.5?

Dr. BODEN. That's right.

Mr. FULTON. Thank you.

Mr. DIXON. In summary, sir, we visualize the ion engine is certainly technically feasible.

Mr. FULTON. Could I just finish that? Is there a difference between the earth gravity then at 31.5 acceleration feet per second and what it is in space?

Mr. BODEN. Oh, yes. The gravitational force drops off inversely as the square of the distance from the earth.

Mr. FULTON. When I say 31.5, I am limiting it only to earth g's. As a matter of fact, you are speaking in space——

Mr. BODEN. We try and take a down-to-earth view of this when we say the thrust-to-weight ratio is 10 to 10^{-4}, that is the thrust-to-weight ratio at the earth's surface.

Mr. FULTON. So you get quite a different ratio as you move out.

The CHAIRMAN. Let's proceed with the testimony and summary.

Mr. DIXON. The ion is a technically feasible project. We visualize the device can be had in 5 to 6 years, and we think the first applications will be a low-altitude satellite, orbital control, and of course eventual establishment of a reconnaissance or stationary satellite that the country is interested in.

The CHAIRMAN. Thank you very much. I don't believe I have asked you, sir, in reference to your research-and-development program. Could you give us that for the record?

Mr. DIXON. We have a research program. We actually have a research model of an ion engine similar to this in a smaller size operating every day. We visualize, and we hope that this research phase will proceed to a development program.

The CHAIRMAN. All right; thank you very much.

Now we have Dr. Daniel Bershader, manager of the Gas Dynamics Department of the Lockheed Missile & Space Division, of Lockheed Aircraft Corp.

Doctor, we will be happy to hear from you.

Before we do that, may I complete the record with the General Electric? They did not give us the extent of their research and development program.

Mr. FTHENAKIS. On this power sources, it is quite extensive, sir.

The CHAIRMAN. All purposes, research and development?

Mr. FTHENAKIS. The research and development is quite extensive. As you know General Electric has a number of departments.

The CHAIRMAN. We don't want to put you to a great deal of work, but if you could compile that and give it to our staff for the record we would like to have it.

Mr. FTHENAKIS. This will amount to around $50 million, but I have to indicate it.

The CHAIRMAN. It is a sizable program then.

Mr. FTHENAKIS. It is more than that. I cannot give an exact figure of the size.

The CHAIRMAN. If you could get the total overall research-and-development program and then the amount you are spending on this space program, too.

(Such information in detail has not been received from General Electric. However, the corresponding data also requested of Dr. Bershader are as follows:)

Lockheed's Missile and Space Division has 17 senior-type scientific personnel doing research and development in electric propulsion; about 50 concerned with electrochemical conversion; and about 200 others in closely allied research and development activities.

The CHAIRMAN. Dr. Bershader.

STATEMENT OF DR. DANIEL BERSHADER, MANAGER, GAS DYNAMICS DEPARTMENT, LOCKHEED MISSILE & SPACE DIVISION, LOCKHEED AIRCRAFT CORP.

Dr. BERSHADER. Mr. Chairman and members of the committee, I realize that the time is growing a little short and some of the other speakers have mentioned points that are pertinent to my presentation. So I will try to be reasonably brief.

I should mention that my own background has concerned the basic research phase of the subject. I, myself, do not do astronautical design engineering, but rather attempt to increase the storehouse of information available to such engineers.

As a matter of fact, Lockheed, because of its interest in expanding our knowledge of the fundamentals underlying such applications as electric propulsion, sponsors a magnetohydrodynamic symposium every year attended by invited specialists.

The idea behind any rocket is an old one and stems directly from the conservation laws of physics. Just as with the release of an inflated balloon, the expulsion of gas in one direction propels the body itself in the other direction. So-called ion or plasma engines make use of electric or magnetic techniques to facilitate this process.

The question then comes up—and Dr. Giannini touched on this: Why do we want to use electric propulsion when we already have chemical propulsion as a rather well-developed method, both in the liquid and solid propellant phases.

As a matter of fact, to compare chemical and electric propulsion and say that one is better than the other, I think, is not very fruitful because in a way that is like comparing apples and oranges. These are different fruits and they each have their own points.

That the two propulsion methods serve different purposes becomes clear if one compares them with respect to two basic performance features: (1) Thrust-weight ratio, and (2) specific impulse. It is a fact that the chemical rocket far exceeds the ion or plasma rocket with respect to thrust-weight ratio whereas the reverse is true with respect to specific impulse. The thrust-weight ratio is an indication of how easily the rocket can overcome gravity. Thus, you would, in fact, want to get off the earth, generally speaking, with some sort of chemical rocket.

Once you are in outer space, the effect of gravity is lowered considerably but one is faced with another type of problem. You ask the question: How can I make these very long space journeys without having to carry the tremendous amounts of propellant required for chemical rocketry? Can I use a device which perhaps doesn't have as much thrust-to-weight ratio, but can get me more for my money in terms of greater progress on the part of the rocket for each pound of propellant that is used during a given time interval. This relates directly to the "specific impulse," mentioned above.

A logical procedure would be to combine the two types of propulsion, using a chemical rocket to attain, let's say, an earth satellite orbit. Then use an electric type of propulsion or something with an equivalent specific impulse to go from, let's say, an earth orbit to a Mars orbit.

To deliver a certain payload, let's say 1 ton, into a Mars orbit from an earth orbit, it would take much less original weight if you use electric propulsion because of the higher specific impulse. At the same time you would want to use some chemical method to reach the earth orbit initially.

Now, the fact that the electric rocket has a small thrust-to-weight ratio—as a matter of fact, the value of 0.0001 g is commonly accepted—has certain advantages because such small accelerations will aid in vehicle control on particular space journeys. You may, for example, desire a rendezvous with another craft in a particular satellite orbit. Careful control of flight path, and therefore of acceleration programing, is important in this instance.

Enough on that particular point. Let us return to the principle of electric propulsion. I have given discussion on this subject in my prepared statement. I would like also to mention that the basic ideas involved here are not new either. Physicists have worked with electron and ion accelerators for many years. The cyclotron and other types of accelerators are in fact beams of ions or electrons as the case may be, streaming through a designed enclosure. If the design were such as to make use of their momentum and thrust in one direction to propel a vehicle in the other direction, you would in fact have had the electric type rocket some time ago.

As a matter of fact, the television picture tube has a great deal of similarity to an electric rocket, because electrons are being boiled off the filament and subsequently accelerated by a high voltage electrode farther down the tube. This pulls electrons into a directed beam to impinge on the screen and produce the observed luminescence.

In the case of the rocket, it is not electrons. With the electric rocket, it is, let's say, cesium ions, which has been mentioned as a very good type of propellant. These stream out of the rocket nozzle after being accelerated and produce thrust.

Mr. McDONOUGH. Why are cesium ions good propellants?

Dr. BERSHADER. Because the cesium atoms are easy to ionize. Cesium, potassium, and sodium are in the so-called alkali metal series. Their atomic structure is such that one loosely held electron is found wandering around the outer shell. It is not too much trouble to detach it completely and thus produce an ion.

The cesium atom comes out of an atomic boiler like vapor from a teakettle. It then can be made to strike a hot tungsten surface—tungsten happens to be a good surface for this purpose—resulting in what is called contact ionization. Accelerating electrodes are used to produce a directed beam in the thrust chamber.

The CHAIRMAN. You use that because it breaks down easily?

Dr. BERSHADER. That's right, Mr. Brooks.

A very schematic diagram of the ion rocket has been given in my statement.

I want to differentiate a little bit between the ion and plasma rocket. In the case of a plasma rocket one does not have a beam of singly charged particles the way one does in an ion rocket, but one has material that has been heated suddenly to a high enough temperature to ionize it. It takes energy to ionize a gas and thermal energy can do it, if the temperature is high enough.

A good way to produce ionization is to promote a strong discharge between two electrodes as shown in the second schematic diagram in my prepared statement. This heats up the gas sufficiently so that some electrons and some ions are formed. In the plasma case, as opposed to the ion case, the gas is neutral as a whole, but because of the thermal pressure buildup, the gas will stream out of the rocket, giving some initial thrust. Then, as some of the other speakers have indicated, one can further accelerate the plasmatic gas by electromagnetic means.

I would like to give a brief example of what I mean. It does not concern a rocket design. This is a laboratory experiment that has been performed at Lockheed and several other places, in which one has what is called a T-tube. (See fig., p. 208.) Two electrodes attach to some high-voltage energy storage utilizing condensers. By proper switching arrangements, one can produce a very strong spark between these two electrodes and very high current flows for a short time. This, again, is a laboratory experiment, not a rocket chamber design.

But now the idea is this: There are many thousands of amperes flowing for a small fraction of a second. As part of the spatial arrangement, there is a "backstrap" very close to the end of the T-tube. Since the circuit is a closed one, the strap current and plasma current are oppositely directed.

Now, the basic laws of electricity predict that two wires carrying currents in opposite directions repel each other. Here, the backstrap

current "repels" the plasma and drives this gas down the tube, thus adding an effective pressure to that which already exists.

Mr. McDONOUGH. You mean that is the basic principle of an ionized rocket?

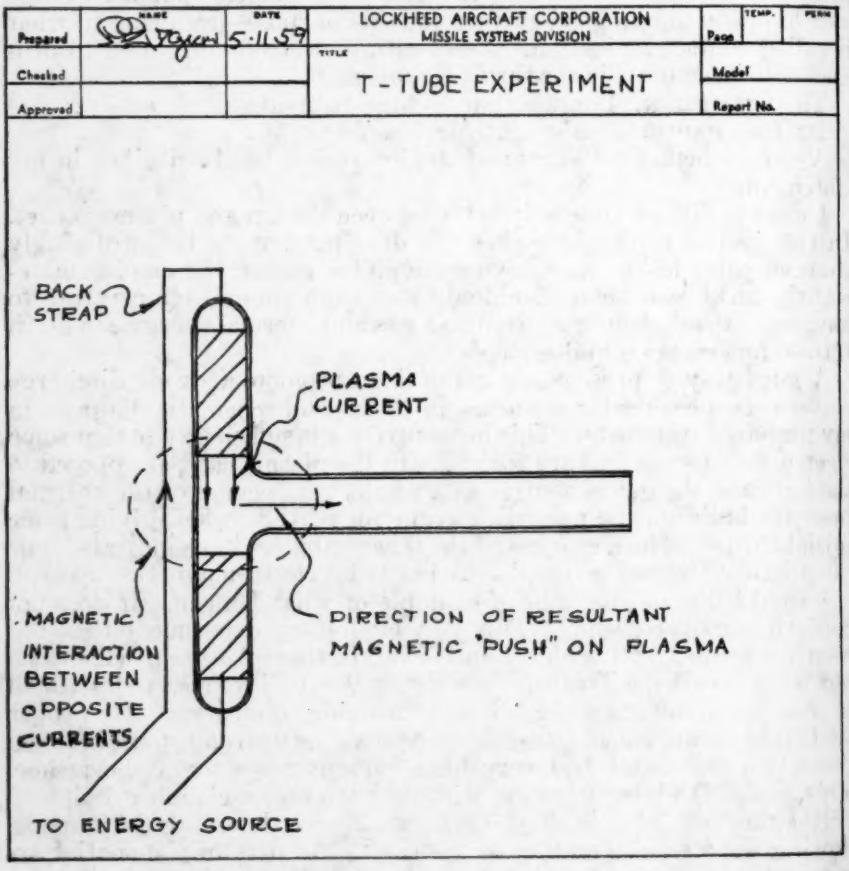
Dr. BERSHADER. It is in a sense a basic principle of a plasma rocket, sir, rather than an ionized rocket.

Mr. McDONOUGH. Propulsion, though, that will give you the forward thrust.

Dr. BERSHADER. That is right. The reason that the plasma rocket is of considerable interest is that one deals with a really new science here, a combination of mechanics and electricity and magnetism which has been given the ponderous name of magnetohydrodynamics. A good deal has yet to be learned about it from a basic point of view before we can assess the applications with better perspective.

That is all I have to say, gentlemen. Thank you.

(The figure referred to is as follows:)



(The prepared statement of Dr. Bershader is as follows:)

INTRODUCTION

Extension of space flight beyond points in the near solar system will require a propulsion method having higher performance than the chemically powered rockets with which we are familiar. Schemes which are in the general category of electromagnetic propulsion have been suggested.

Indeed, this field is a fruitful one for the imaginative astronautical engineer. The basic physical features of an electromagnetic propulsion system are different in principle from the chemical type in that electrons are stripped from the atomic particles of the propellant, thus destroying their electrical neutrality.

The resultant material, consisting of large numbers of free electric charges, can be accelerated from an exhaust nozzle by properly located electric/magnetic field forces. The reaction to such change in momentum of the charged particles or ions, is an impulse which propels the space vehicle itself in the opposite direction. Two somewhat different versions, the ion engine and the plasma engine, will be discussed later.

Our understanding of the intrinsic physical behavior of such systems is still somewhat primitive. This stems from the complexity of the behavior to be expected when a combined form of two major disciplines—namely, fluid mechanics and electricity—is required for its description. It stems as well from the difficulty of performing appropriate laboratory experiments with proper simulation and control of parameters. There exists a clear need for further research and development.

MAJOR PERFORMANCE FEATURES OF ION AND PLASMA ENGINES

A comparison of some characteristics of chemical and electromagnetic engines is given in the table:

Engine	Maximum specific impulse (sec.)	Thrust-weight ratio
Chemical	350	150
Electromagnetic	20,000	1/10,000

The numbers can be considered as typical.

Now, the thrust-weight ratio is a measure of the acceleration of the vehicle in the terms of the acceleration of gravity, denoted by "g." To leave the ground and reach sizable velocities in a reasonably short time, the chemical engine is needed. Once the vehicle is reasonably free of planetary gravitational fields, only very small thrusts, corresponding for example, to 10^{-4} g, are needed for control of the motion.

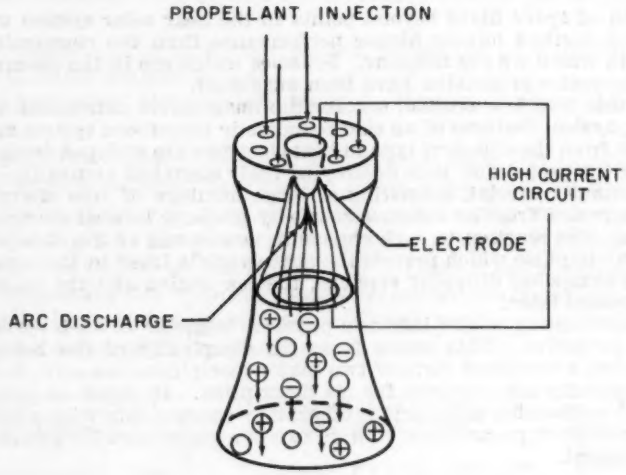
On the other hand, if it is desired to maintain a satellite motion at relatively low altitudes, such as around 200 miles, only a small thrust is necessary. It takes only a small thrust to counteract the small amount of drag due to the very thin atmosphere, or other possible causes, such as electromagnetic drag. Given enough time, appreciable velocities may be achieved in spite of the small acceleration. Thus, low-thrust engines may be useful in a number of other applications, such as orbital transfer and rendezvous operations, as well as interplanetary travel.

The high specific impulse associated with the electromagnetic engine implies a highly effective usage of the available propellant material. This is clearly of importance for extended orbital operations or long space journeys. One cannot afford to use up too much material in a given period of time in such applications.

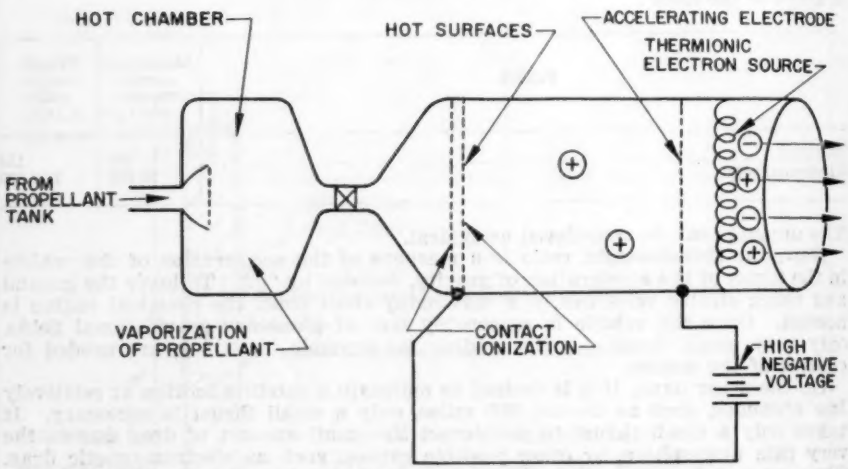
High-performance, low mass-loss operation is a result of maximizing the ejection velocity of the propellant particles. Preliminary experiments performed at the Lockheed Scientific Research Laboratory and elsewhere indicate that electromagnetically ejected particles can be given velocities 50 to 100 times higher than the material exhausted from chemical rocket engines. Thus it is evident that, in a sense, chemical and electromagnetic propulsion are not in competition, but in a complete space flight operation, they would complement each other.

DESCRIPTION OF ELECTROMAGNET ENGINES

First, let us consider the so-called ion engine.



PLASMA ROCKET ENGINE



ION ROCKET ENGINE

The most suitable source material appears to be one of the active alkali metals such as cesium. It takes a comparatively low energy to remove the most loosely bound electron from the cesium atom and thus ionize it. Probably liquid cesium from a storage tank would be injected into a hot chamber, producing vaporization. The vapor would then flow through suitable nozzles and impinge on hot surfaces, possibly made of tungsten, producing contact ionization.

A combination of a baffled arrangement and local electric fields would maximize percentage of ionization. A large negative voltage applied to an accelerating electrode in the form of a grid or honeycomb speeds up the positive ions after which they are ejected. There is a problem of maintaining overall electrical neutrality on the vehicle.

Because of this, it appears desirable to include a thermionic electron emitter (a heated filament or surface of some sort) to eject negatively charged electrons. There are, of course, many questions of engineering design which arise. One in particular is the possibility of space-charge effects adversely affecting the ion acceleration between electrodes. Again, the need for further laboratory research is implied.

Although the ion engine just described might be termed an "electric device," the plasma engine is more truly electromagnetic. One starts with some suitable gas which upon entering the pressure chamber is suddenly heated by a high current arc discharge between strategically placed electrodes, or by a high current induced a strong electrical pulse through a coil which surrounds the chamber. Under such conditions, a substantial portion of the gas is ionized The term "plasma" applies generally to such mixtures of ions, electrons, and residual neutral atoms.

By strategic placement of electrodes and auxiliary accelerating magntic fields, it is possible to accelerate the plasma through an exhaust nozzle, thereby providing the desired thrust. The plasma device has the advantage of avoiding the space-charge problem since the material is neutral in the discharge chamber. It is likely that the plasma engine would be smaller than the ion engine.

POWER SUPPLY

The problem of power supply and energy conversion is a critical one for electromagnetic engines. The figure of $\frac{1}{10,000}$ thrust-weight ratio implies that approximately 10,000 pounds of power supply are needed to produce 1 pound of thrust. The most promising source of energy is a nuclear reactor which would use either liquid sodium or helium as a working fluid. Heat carried by the fluid could be used to operate a turbine generator to supply electrical energy vaporization, or ionization, as required. Such a powerplant has considerable inert weight and is still undesirable in spite of recent improvements in design.

An improved version which is undergoing considerable developmental effort makes use of a nuclear reactor to heat thermionic cells. Such cells when heated produce electric currents, thus generating the electric power required for electromagnetic propulsion.

Again, a fluid could be used for the heat transfer, but attention is being devoted to use of radiative heat transfer. The arrangement here would have the nuclear reactor inside a shell the outside surface of which consisted of thermionic cells. This has the added advantage of dissipating excess heat.

MAGNETOHYDRODYNAMICS

The term "magnetohydrodynamics" has been used to describe the science underlying the basic behavior of plasma rockets. It is applied to other technological activities also, especially in the research under Project Sherwood, the program designed to make useful thermonuclear power a reality. It is the name given to the rather complex combination of fluid dynamics and electromagnetics needed to describe the motion of conducting fluids in rocket nozzles or elsewhere. Only within the last few years has this field received systematic attention on the part of research groups.

In fact, the schematic diagram illustrating the plasma rocket approximates a geometry that is being tested in the Lockheed laboratory. A sudden discharge from a high-energy condenser bank produces a strong spark between the central electrode and the second ring-shaped electrode. The discharge takes place in several millionths of a second, during which the working gas is heated and ionized.

Instead of an open-end rocket nozzle as shown, the laboratory experiment permits a strong shock wave to travel down a closed tube, previously evacuated to a low pressure. The shock wave is a strong pressure wave, but it is followed by high-speed material, including some that was evaporated from the electrode itself.

Because of the intense luminosity radiated by the hot material behind the shock waves, speed of the plasma can be monitored by a very high-speed camera (exposure time one-twentieth of a millionth of a second). In such experiments, speeds approaching 200,000 miles per hour have been observed, giving further verification that plasma propulsion schemes yield the very high specific impulses described earlier. (Final velocity of the ejected particles is a direct measure of the specific impulse.)

In another laboratory experiment performed at Lockheed, a wire is made to explode by an appropriate discharge, the evaporated wire material then serving as the working plasma. Thrust measurements have been made on a laboratory scale, indicating an efficient conversion of energy.

Evaporation of electrode material itself probably contributes to the plasma. Other special phenomena take place, including the so-called pinch effect, various types of instabilities, and new types of wave motion over and above the usual sound and shock waves. In any given engineering design, one or more of these phenomena can play a role which affects the successful performance in a critical fashion.

It should be stressed, then, that fundamental research in magnetohydrodynamics, in addition to development of engineering designs, requires a high level of support. The research program at Lockheed and several other laboratories reflects this need, as does our annual Symposium on Magnetohydrodynamics.

FINAL REMARKS

The field of electromagnetic propulsion shows considerable promise for satellite and space vehicle applications. It complements chemical propulsion which is still needed for getting the craft off the ground.

Ion engines appear to have reached some working state of development, with more work required for improved performance, especially in the power supply.

Plasma engines are in a more primitive stage of development. Although they show much promise in principle, more research on fundamental magnetohydrodynamics is prerequisite to more systematic progress in this area.

The CHAIRMAN. Thank you very much, Doctor.

I am going to call on Mr. Y. C. Lee. We can hear Mr. Lee. He is our last witness. Then if we want to ask any questions we would have to let this go over until tomorrow because there are going to be several rollcalls this afternoon. We will just simply be chopping this up every few minutes.

So we will call on Mr. Lee, director of corporate research of the Aerojet-General Corp. from California.

STATEMENT OF MR. Y. C. LEE, DIRECTOR OF CORPORATE RESEARCH, AEROJET-GENERAL CORP.

Mr. LEE. Thank you, Mr. Chairman. First of all, I would like to say I don't want to burden you gentlemen with the technical details. I have a three-volume dissertation, technical details on electrical propulsions systems. It is classified "Confidential." However, I believe it is appropriate at a later time to submit to the committee for consideration. I have talked with Dr. Sheldon on this.

The CHAIRMAN. I agree with you, Mr. Lee. I feel this way, that we are not scientists and if a member of the committee wishes to get deep into the technical formulas of science, perhaps we better arrange for him to do it on the side, rather than the full committee.

Mr. LEE. Yes, sir. So in the interest of time I think you gentlemen will be interested in three things actually. These three things are: Why do we need an electrical propulsion system? Secondly, what kind of electrical propulsion system do we need in the light of our space programs both from the standpoint of defense as well as scientific exploration. Thirdly, I would like to point out, how are we going to achieve this objective? I think previous speakers have indicated why electrical propulsion systems. I would like to add just a few words on this. I think we have a requirement today which needs the electrical propulsion system at this moment.

For example, the communications satellites, the weather satellites, either military or scientific, they need an attitude control system. They need to be able to operate for a long duration, a year, possibly more. Because of these factors we need electrical propulsion systems. The technical reasons why, namely, they have very high specific impulse, their weight of propellants is less than other types of propulsion systems.

Another thing I would like to mention, militarily speaking—again I don't think this is in the area of security—is if a satellite is to be used for military means, it must be able to change its orbit on command. At the present time our satellite is going around the earth and the orbit is completely predictable. If it is completely predictable, it is militarily not too useful. Therefore we must have an electrical propulsion means to change the satellite orbit on command for military use.

So with this introduction I think it is pretty well agreed upon we need electrical propulsion systems which can give you high specific impulse, and corresponding long duration of operation.

The next thing I would like to say is what systems are we talking about, and in particular what kind of system so far as our Government is concerned should their money be put into? You have heard our colleagues from California discuss ion propulsion and discuss magnetohydrodynamic acceleration, discuss plasma jet. I think there are some criteria you gentlemen probably would like to know. The No. 1 criterion is: How many pounds of thrust can you get in relation to the total weight of the system; to put it in the technical language, it means the net acceleration of the system. In other words, it is the thrust-to-weight ratio of the system.

This is a number that is important because if the number is too small, it means you take a long time to accelerate your payload, to get where you are going. This may not be useful, particularly if you talk about manned systems, and there is an optimum. If you take too long to get there, the time required and the weight required to support a man may overcome the usefulness of such a propulsion system.

For example, ion propulsion system, I think, as has been mentioned, has a thrust-to-weight ratio of 10 to the minus fourth. This means you have 1 pound of thrust for each 10,000 pounds of weight. You can compute that it would take you something about 350 days—a year roughly, for a Mars mission. We talk about lunar missions.

Obviously this kind of system with a 10 to the minus fourth g is not very useful for a lunar mission. So the No. 1 criterion is: How many pounds of thrust can you get in relation to total weight?

Secondly, is the system reliable? One thing you can say is that you certainly don't want a system that is operating at high temperatures, say temperatures on the order of 1,500° F. or 2,000° F. in the case of ion using cesium, because you can't have material operating at those temperatures for a year. It is not reliable.

No. 3 question: How much power you need in order to accelerate your ions. We are talking about accelerating ions to half a million feet per second. I think Mr. Fulton indicated that acceleration on the order of 1 mile per second is very high. To accelerate to that high speed you need high power.

The CHAIRMAN. Mr. Lee, I am very sorry, but here is what you are running into now. There is a rollcall on the floor. These members here are getting restless because this is the second bell. That is the last bell to make the rollcall. We are due to have several this afternoon. We haven't really given you a fair opportunity to present what you are doing in such a capable manner.

Mr. LEE. Thank you, Mr. Brooks.

The CHAIRMAN. We have no alternative, though. They moved the opening of Congress up this morning from 12 to 11. We didn't know about it.

I suggest this: We have a very heavy schedule in the morning, too. I am going to suggest that our technical director, Dr. Sheldon, meet with you gentlemen, if you have the time. You can meet right here. Our technical director, together with those that he needs to help him, might go over this and elicit the questions that the committee might otherwise ask you.

In that way we will preserve your testimony for the use of the committee. We would appreciate it very much if you would cooperate.

Mr. MILLER. Mr. Chairman, may I say I am very happy to see Mr. Lee here. Where are your headquarters, Mr. Lee?

Mr. LEE. In Azusa, Calif.

Mr. MILLER. And to see Dr. Bershader who comes from Stanford.

The CHAIRMAN. Well, California is well represented here in witnesses and on the committee, too.

(The prepared statement of Mr. Lee is as follows:)

I. INTRODUCTION

A. It appears appropriate to discuss electrical propulsion systems on the basis of—

1. Brief description of the electrical propulsion systems currently contemplated.
2. Some applications to space systems for national defense and scientific exploration.
3. The present state of the art.
4. Conclusions and recommendations.

II. DESCRIPTION OF THE ELECTRICAL PROPULSION SYSTEMS, APPLICATIONS AND PRESENT STATE OF THE ART

A. The electrical propulsion systems can be essentially divided into charged particle systems and plasma systems. The charged particle systems may include the ion propulsion system and charged colloidal propulsion system. The plasma system may include the plasmajet and a plasma acceleration propulsion system.

These systems consist of essentially a nuclear power source, conversion equipment to convert nuclear energy into electricity, the thrust device which includes the sources, the focusing device, acceleration device, and neutralization device.

All electrical propulsion systems are characterized by low specific thrust, high specific impulse, and its capability of long-duration operation. Because of their low specific thrust, defined as thrust-to-weight ratio of a propulsion system, these propulsion systems are necessarily restricted to space applications. In other words, they cannot perform the task of takeoff from earth.

B. One of the most popular electrical propulsion systems is an ion rocket using one of the alkali metals, usually cesium because of its ease of ionization. Cesium has been used for experimental work in the laboratory. However, its availability, and therefore cost, makes it doubtful for use with a flyable propulsion system.

A major requirement for the development of an ion source probably will use other alkali metals, capable of operation over a long period of time. It can be shown that for an ion rocket the optimum specific impulse occurs at about 10,000 sec, with a corresponding specific thrust value of approximately between 10^{-3} g. and 10^{-4} g. Other problems associated with ion rockets are those of focusing the ion beam, or, to put it differently, of getting the beam out of the rocket in the direction and with the velocity required.

If it is visualized that the ion beam having currents up to 100's of amperes, it represents a problem of considerable magnitude. Problems of space charge, erosion of the electrodes, operation at elevated temperatures for long durations, and the maintenance of the electrical neutrality require investigation on a much larger scale than has been to date.

C. Because of these problems and particularly the high-temperature problems associated with ion propulsion, consideration of charged colloidal propulsion appears promising. Currently, Aerojet is performing research on a charged liquid colloidal rocket. These microscopic liquid particles are many orders of magnitude larger than ions and have a much smaller charge-to-mass ratio.

Laboratory investigations of the charged liquid colloidal source have shown a specific impulse of about 2,000 sec, can be obtained with a corresponding specific thrust value of about 10^{-2} g and 10^{-3} g, although the theoretical limit is about 8,000 sec.

The chief advantage of the charged liquid colloidal system lies with the reliability which results from the low-temperature source. Also, the use of the charged liquid colloidal system will reduce the power requirements per pound of thrust.

Therefore, it is capable of delivering larger thrust and higher specific thrust for a given energy source at reduced weight. It appears that the problems of focusing, aceleration, and neutralization are much easier to solve. It is anticipated that with adequate funding a charged liquid colloidal propulsion system could result in a flyable prototype in a period of approximately 5 years, based upon the current technology of nuclear power source and conversion equipment.

Insofar as ion propulsion is concerned, current state of the art indicates that high-temperature source is feasible. However, a high-temperature source is not considered reliable from the standpoint of reliability because of operation at elevated temperatures and for long durations.

D. The plasma systems have not been as precisely defined as the charged particle systems. The plasmajet which utilizes an electrical arc to heat the gases to extremely high temperatures has been demonstrated in the laboratory. The high-temperature gases can then be directed to produce thrust by hydrodynamic expansion.

With the plasmajet, it appears feasible to obtain a specific thrust value of approximately 600 to 800 sec, with a corresponding specific thrust value of about 10^{-2} g to 10^{-3} g. The accelerated plasma system is less defined than any of the other electrical propulsion systems.

Although some laboratory experiments have been conducted to accelerate a plasma by the use of magnetohydrodynamic techniques, it is generally agreed that there is considerable doubt as to its practicability as well as feasibility.

Obviously, there are considerable material problems in handling gases at extreme temperatures for the plasma systems. In any case, there is much experimental work to be done to explore the possibilities of the plasma system. These investigations will necessarily be of a fundamental nature.

E. From discussions indicated above, it appears that each of the systems discussed has its distinct area of application. Insofar as ion propulsion is concerned, it is only useful for interplanetary space missions. This is because of its relatively high specific impulse and low specific thrust values.

By the same token, the charged colloidal propulsion system has its distinct area of application for satellite and lunar missions, and possibly interplanetary missions. This is because of its capability of relatively high specific impulse and relatively high specific thrust values.

For example, it is visualized that the charged colloidal propulsion system can be used for attitude control connected with a communication and a weather satellite. In addition, from the standpoint of national defense, a satellite should have the capability of changing its orbit on command. This capability, it appears, can best be obtained by the use of a charged colloidal system.

III. CONCLUSIONS AND RECOMMENDATIONS

A. It is generally agreed that a need of an electrical propulsion system is well established and that they are a definite necessity for long-duration operation in space. In particular, the need of an electrical propulsion system to effect attitude control as well as orbit changing is of prime importance.

Common to all the systems is the requirement for a lightweight, highly efficient, nuclear powerplant. In appreciation of the extreme importance of

weight and efficiency of the nuclear powerplant, it can be shown that approximately 90 percent of the overall system weight is represented by the nuclear reactor, conversion equipment, radiator, and other associated components.

Therefore, the development of such nuclear powerplants should be accelerated with the utmost vigor. The next area requiring added effort is the investigation of the thrust-producing system on an integrated basis. This means a technical development program to investigate the problems and interplay associated with the sources, focusing, acceleration, and neutralization with a view to obtain design parameters for a prototype.

Another area requiring accelerated effort is direct power conversion methods. Direct conversion methods offer potential advantages in reducing system weights and improving system reliability. A further requirement is the need for a nuclear reactor which incorporates a thermionic or thermoelectric converter. To place increased emphasis on research and development of direct conversion methods is essential.

B. Finally, it appears appropriate to indicate that although there is no evidence that Russia is ahead of us in electrical propulsion systems, it is a safe assumption that they are. If this assumption is accepted, an integrated technical development program leading to a flyable prototype should be initiated at the earliest possible date. It can be said we have requirements today that will have definite needs for this kind of propulsion systems in the next 3 to 5 years.

The CHAIRMAN. The committee will stand recessed until tomorrow morning at 10 o'clock.

(Whereupon, at 11:15 a.m., the committee recessed, to reconvene at 10 a.m., Friday, March 20, 1959.)

(The following testimony was given before Dr. Charles S. Sheldon II, technical director of the committee, representing the full committee in its absence.)

Mr. LEE. Another criterion is the problem area associated with any of the electrical propulsion systems. In a sense, whether or not they are easy or difficult to resolve.

Based upon the aforementioned four criteria, it appears:

1. As far as ion propulsion is concerned, it has a high weight with a relatively low thrust.

2. It is operating at elevated temperatures, thereby it appears to impair its reliability.

3. It requires high power. This implies a large nuclear reactor, heavy weight.

4. It implies the problems associated with high ion current, focusing problems, acceleration problems, and space charge problems, and space neutralization problems which are difficult to resolve.

The same unfavorable conditions apply to the plasma systems. This plasma system could be a plasma jet or a plasma jet accelerated by the technique of nagnetohydrodynamics. They have the same disadvantage as the ion propulsion systems, particularly from the standpoint of high temperatures.

There is one electrical propulsion system that has not been mentioned by any of the previous speakers, nor does it appear very extensively in literature. This is the propulsion system known as the charged colloidal propulsion system.

At my company, Aerojet-General Corp., we have been performing research on the charged colloidal propulsion system on a company-support basis. We are currently negotiating with the military to obtain a research contract.

Our laboratory results to date indicate that the charged liquid colloidal propulsion system has relatively low weight per pound of

thrust. In fact, it is capable of delivering tens or hundreds of pounds of thrust, rather than quarter of a pound of thrust in case of the ion propulsion.

The charged colloidal propulsion is operated at low temperatures—in fact, ambient temperatures. Thereby it is considered reliable, and it does not require acceleration to high velocities, and therefore it minimizes the power requirement and therefore weight.

The problem associated with the colloidal propulsion system is also easier to solve because of the lower acceleration, higher voltage required. Therefore it appears if we are to make a choice as to where to spend our national dollars, it is my personal belief that the charged colloidal propulsion system is one in which we can resolve the problems of obtaining a prototype—in fact, a flyable prototype—in 3 to 5 years.

In conclusion, I would like to say some of the electrical propulsion systems are not well defined. They need support on the basis of fundamental research. Some of the other electrical propulsion systems are well along from the standpoint that it has been demonstrated in a laboratory as to its feasibility.

In particular, we feel the charged colloidal propulsion system is one in which it does not require scientific breakthrough and it can be developed in 3 to 5 years by a relatively extensive technical development program in which the problems of power supply, conversion equipment, power supplies, and thrust device can be investigated on an integrated basis to obtain design parameters leading to the prototype.

It can be used for satellite and lunar missions, for guidance and control, as well as propulsion.

Finally, it appears appropriate to say that, although there is no evidence that Russia is ahead of us in electrical propulsion systems, it is a safe assumption that they are. If this assumption is accepted, an integrated technical development program leading to a flyable prototype should be initiated at the earliest possible date.

Dr. GIANNINI. At the Plasmadyne Laboratories we have operating plasma-accelerating devices every day. In fact, we have made and sold approximately two dozen of them to industry, including North American, Aerojet, Thiokol, GE, Douglas, and so forth.

To our knowledge the plasma accelerators are in operation today for experimental purposes in all of these places that we have made. In other words, we made more practical devices that work, and sold them, than anybody else.

(End of supplemental testimony.)

SPACE PROPULSION

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C., Friday, March 20, 1959.

The committee met at 10:05 a.m., in room B–214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. The committee will please come to order.

We are continuing this hearing on propellants and we have Mr. Richard J. Coar, chief engineer, Pratt & Whitney Aircraft, Florida Research and Development Center, at West Palm Beach, Fla., here today to talk on the special problems of hydrogen-fueled rockets.

Then we have a group of witnesses who wish to be heard in executive session following this. However, we want to hear these people, first.

Mr. Coar, do you have a prepared statement?

STATEMENT OF RICHARD J. COAR, CHIEF ENGINEER, ADVANCED PROJECTS, PRATT & WHITNEY AIRCRAFT DIVISION OF UNITED AIRCRAFT CORP.

Mr. COAR. Yes; I do.

The CHAIRMAN. Would you wish to proceed with your prepared statement?

Mr. COAR. Yes.

Mr. DADDARIO. Mr. Chairman, before Mr. Coar proceeds, I would like to welcome him in behalf of the committee. This company which he represents is a company from my district in East Hartford. It is a subdivision of United Aircraft. Pratt & Whitney certainly is the type of industry which we are proud of in Connecticut and which I think we should be proud of in the country.

It started back in 1925 with just a dozen people without any Government subsidies, without any Government assistance of any kind, but just an idea of what the air age was about, and with faith in themselves. They operated out of a tobacco warehouse, and from that place they developed an engine which they first sold to the Navy. Then, over the course of time they developed it to the point where today the company employs in Connecticut, in four different communities, and in Palm Beach, Fla., something in the vicinity of 55,000 people.

This is a great success story insofar as American industry is concerned. I am certainly very happy to welcome them here, and I am looking forward, as I am sure the committee will, to the information they will give us.

The CHAIRMAN. Thank you. I want to say this. I know something of that to which Mr. Daddario refers. I had the privilege of visiting and inspecting the Pratt & Whitney Aircraft Center in Hartford during World War II. I haven't seen it since then, but I have a pretty good idea of the magnitude of the work that is being done there.

Mr. Coar, if you will proceed. Do you have extra copies of that prepared statement?

Mr. COAR. I have copies for the committee, sir.

The CHAIRMAN. Fine.

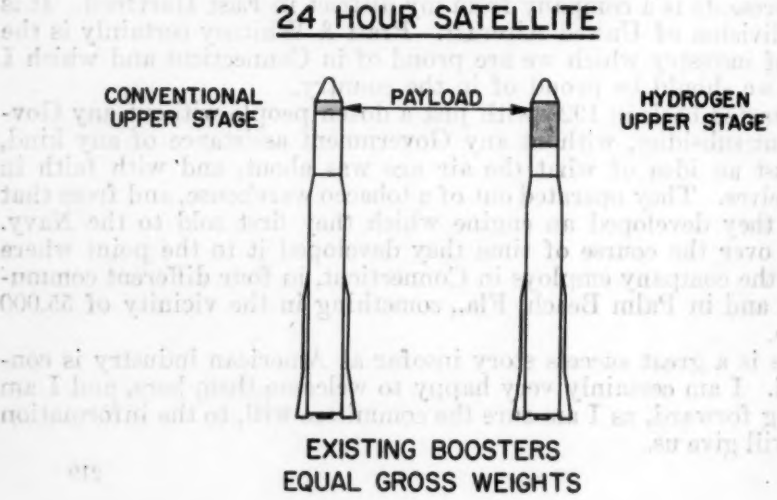
Mr. COAR. We have been asked by your committee to discuss the field of hydrogen rockets. I will try to give you our thoughts on this subject.

Considering that hydrogen makes up more of the universe than any other element, it is not strange that for many years we have been discussing its use in space rocket systems. United Aircraft has been active in a major way for the past 5 years, both studying the application of hydrogen to missile and space systems and also reducing to practice the results of this work. In examining various rocket missions we have found that the substitution of hydrogen for conventional fuels will, as a rule of thumb, double the payload of the system.

You are aware that the first-stage booster is the most expensive part of any space rocket system. Hydrogen-fueled upper stages can increase the payload and can make feasible otherwise impossible missions with a given boster. We believe that this ability is significant to the national economy.

For example, our studies indicate that a hydrogen upper stage on one of today's existing boosters can place in a 24-hour (22,000 mile) orbit over three times the payload of a conventional upper stage.

FIGURE 1

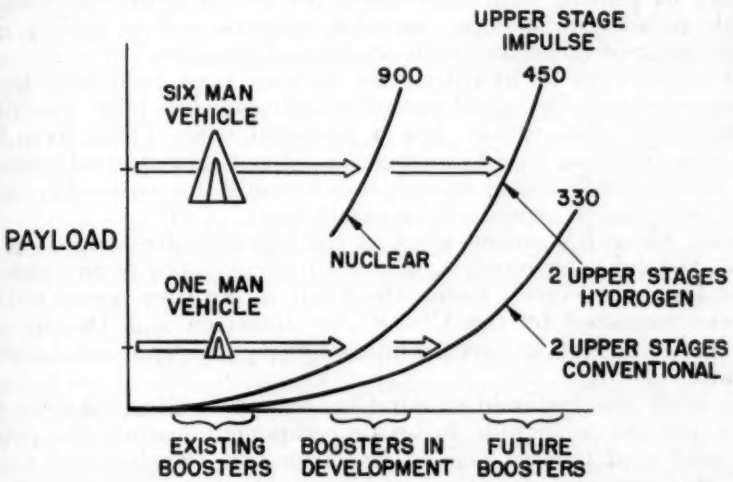


The CHAIRMAN. Dr. Sheldon, did you want to come up here and have a seat in one of these seats where you can see? I imagine if you are writing a report, you will want to see these charts.

Mr. COAR. Looking at another problem, that of sending around the moon and back to earth a manned vehicle capable of reentering the earth's atmosphere, the advantages of hydrogen upper stages are again apparent. Here we see that with two hydrogen upper stages, a large booster stage such as that recently put under development by ARPA or NASA is adequate to put a one- or two-man vehicle around the other side of the moon.

FIGURE 2

EARTH AROUND MOON AND RETURN MISSION



Mr. COAR. It would require clustering several of these boosters to accomplish this mission with lower energy upper stages. On the other hand, two hydrogen upper stages on such a booster cluster could put a sizable vehicle around the moon and return.

The CHAIRMAN. What do you mean by a sizable vehicle?

Mr. COAR. Something that might carry six men, that order or magnitude.

We should also note that this six-man vehicle could accomplish this same mission with one hydrogen nuclear upper stage, using a single booster of the size now under development. These examples are not necessarily typical with respect to mission, but they are typical of the performance gains possible with hydrogen-fueled rocket engines.

In chemical rockets, hydrogen, in combination with fluorine or oxygen, provides about a 40-percent improvement in specific impulse over the conventional LOX (liquid oxygen)-kerosene combination. In spite of the low density of liquid hydrogen, and attendant large tank volumes, this better fuel economy gives the magnitude of payload improvement we have discussed.

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Hydrogen's impulse is only slightly higher with fluorine than with oxygen, and there may be some missions which require exploiting this slight advantage. It would seem doubtful, however, that the hazards introduced by fluorine's toxic and corrosive qualities should be risked in any man-carrying mission.

In nuclear rockets, hydrogen has a specific impulse well over twice that of any other working fluid. At probable reactor operating temperatures, the specific impulse of nuclear rockets using hydrogen will be double that of the best chemical systems.

In the development of earthbound rocket systems such as the ICBM, the performance gains possible with hydrogen engines have not been essential to accomplish the task, although the payload-to-gross-weight ratio could have been improved.

However, now that we are entering the space arena, and talking seriously of putting man into space, the use of hydrogen makes it possible to accomplish more complex missions and to satisfy more difficult payload objectives with economical boosters.

The advantages of hydrogen for rockets have been well known for many years. But until recently hydrogen has been considered a "theoretical" fuel rather than a practical one. There have been many who felt that liquid hydrogen could not be produced economically, that it could not be stored, that it could not be readily transported, and that it could not be safely used.

United Aircraft's serious work in the liquid hydrogen field began in 1955, involving parametric propulsion system studies and research for the U.S. Air Force. Later, the Pratt & Whitney Aircraft Division was requested by the USAF Air Research and Development Command to undertake a major liquid hydrogen propulsion feasibilty program.

This work was initiated at our Connecticut facility. As the program expanded to include full-scale component testing, the project was transferred to our Florida Research and Development Center where the necessary isolation was available for large-scale liquid hydrogen experiments.

The CHAIRMAN. Let me ask you: Give us some idea, if you will, what is the size, nature, and the volume of the work done at that plant in Florida?

Mr. COAR. This facility is entirely a research and development facility, restricted to research and engineering. The floorspace of our facilities here are something over 650,000 feet. We currently employ about 2,400 people, of whom something over 350 are technical: scientists and engineering personnel.

The CHAIRMAN. Is that the entire research and development program, or do you have some of it located elsewhere?

Mr. COAR. This is only a part of our total research and development effort.

The CHAIRMAN. What is your entire effort?

Mr. COAR. I am not sure what our total effort, including our nuclear and our Connecticut effort is, but it is approximately three to four times in the aggregate of what we have in Florida.

The CHAIRMAN. So it would run approximately how much in money?

We are not trying to check up. We are just trying to tabulate the census of the research and development program throughout the country.

Mr. COAR. I don't have the total for our complete Pratt & Whitney Aircraft Division. In Florida, where I am familiar with the number, our operation there is something on the order of a $30 million expenditure per year.

The CHAIRMAN. If you could supply us with that information for the record later, it would be very acceptable to the committee.

Mr. COAR. I will request the information, Mr. Chairman.

The CHAIRMAN. Fine.

Just proceed, sir.

Mr. COAR. This Florida facility gives us the isolation we thought we needed for large-scale liquid hydrogen experiments. Since 1955, the liquid-hydrogen technology in the United States has progressed out of the laboratory, where it was measured in liters, to the point where we can now measure our experience in millions of gallons.

The experience gained by ourselves and the Air Force in this program has indicated that liquid hydrogen can be produced reasonably, that it can be stored practically, and that it can be transported easily. As far as hazards are concerned, we have found that in many ways liquid hydrogen is less dangerous than gasoline. Figure 3 is a view of what we believe to be the largest liquid hydrogen test facility in this country. Typical large-scale storage facilities are shown in figure 4.

(Figs. 3 and 4 follow.)

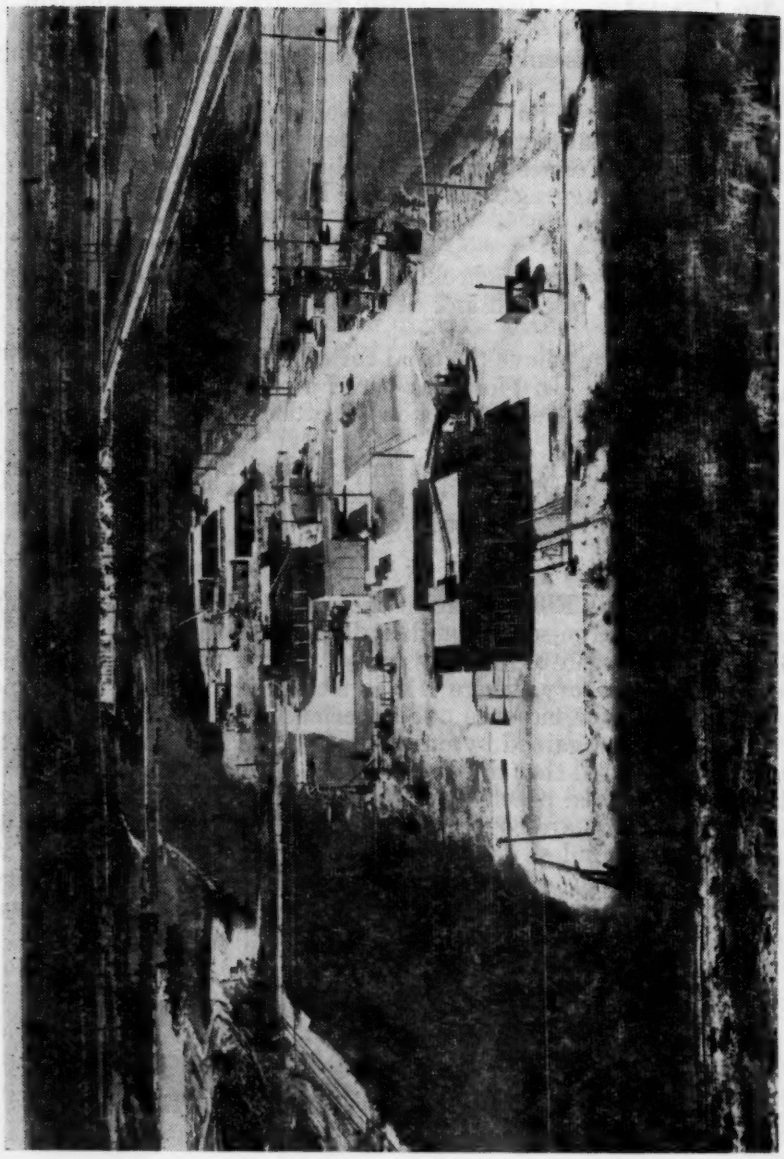


FIGURE 3

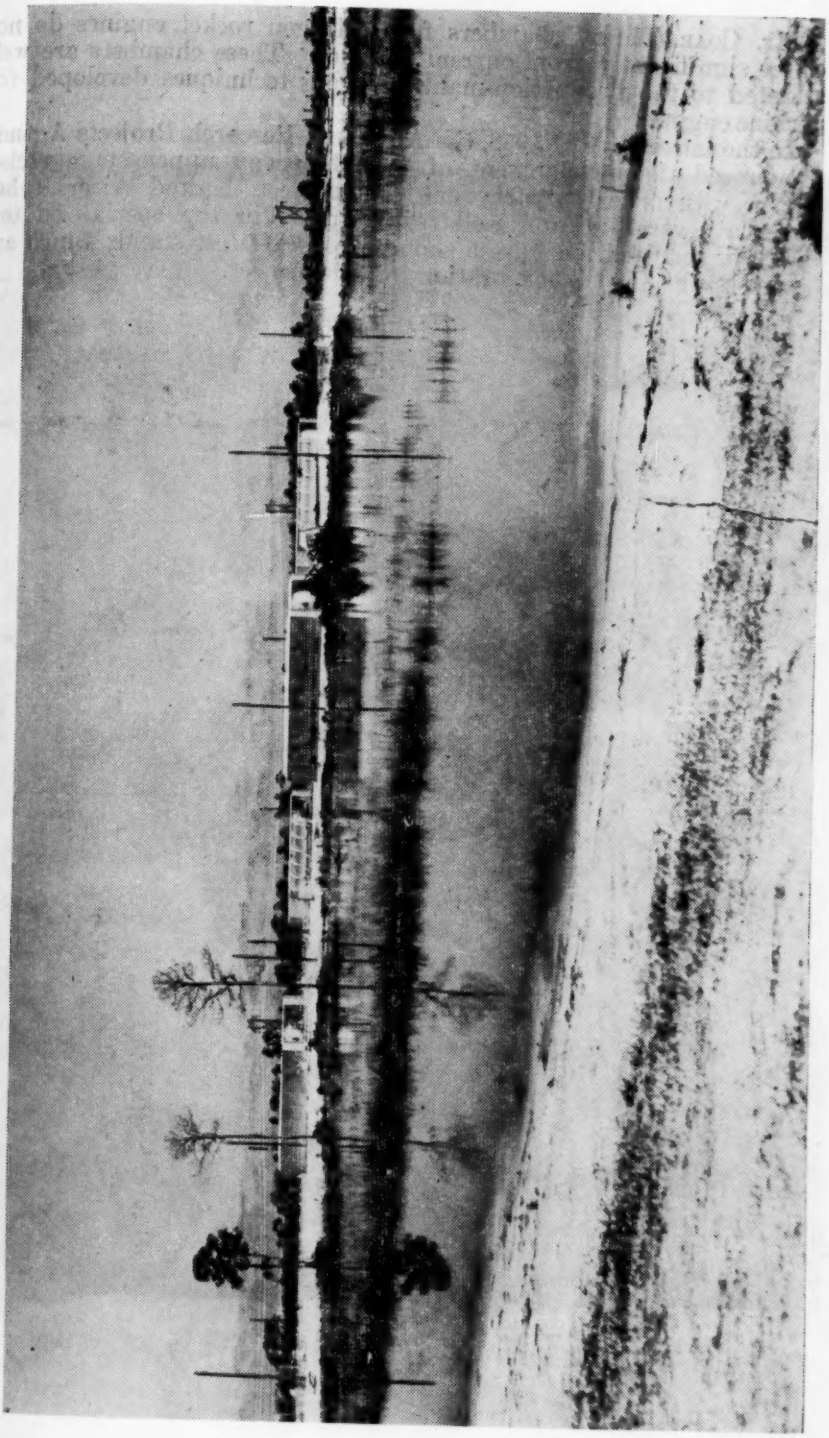


FIGURE 4

Mr. COAR. Thrust chambers for hydrogen rocket engines do not differ significantly from current practice. These chambers are well adapted to the production-manufacturing techniques developed for turbine engines.

In the latter part of 1958, the Advanced Research Projects Agency announced the development of a high-energy upper stage rocket engine. In order to carry out this project, United Aircraft has made a several million dollar investment in the specialized test facilities required. Figure 5 shows the rocket test stands which are being supplied by the corporation for this project.

FIGURE 5

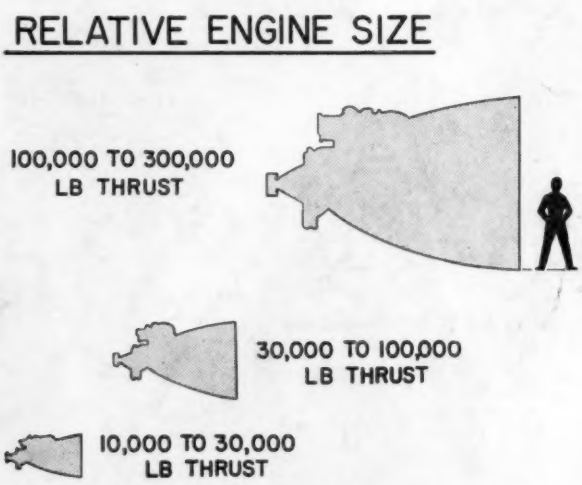
The rocket engine test stands being constructed have a thrust capacity up to 300,000 pounds, and provide for simulation of high-altitude engine starting and running.

SUMMARY

Hydrogen-fueled rocket engines provide a major improvement in the payload which can be put on a space mission with existing or planned boosters. Large-scale experience with liquid hydrogen has shown that it is a practical fuel, and that components can be satisfactorily engineered for service at 423° below zero Fahrenheit.

We believe that development of one hydrogen upper stage engine in each of three categories should fulfill all space mission requirements for existing and planned booster systems (fig. 6) : 10–30,000 pounds, 30–100,000 pounds, 100–300,000 pounds.

FIGURE 6



The CHAIRMAN. Thank you very much, sir. We appreciate your statement.

Mr. DADDARIO. Mr. Coar is from your district. If you wish to start out we will recognize you for the purpose of asking questions.

Mr. DADDARIO. Thank you, Mr. Chairman.

Mr. Coar, in your fourth page you refer to the fact that United Aircraft has made a several million dollar investment in specialized test facilities required. Is that a company investment or is there a contribution in some part on a fee basis with the Government?

Mr. COAR. This represents the corporation investment in these test facilities for this rocket program.

Mr. DADDARIO. In this case that is all private company capital worktoward the research and development of this booster engine which you have referred to.

Mr. COAR. This is an upper stage.

Mr. DADDARIO. I am sorry. There is no connection at all with the Government insofar as this particular investment is concerned?

Mr. COAR. We have had some Government facilities in the course of some of our earlier liquid hydrogen development. Some of these are still being continued. The facilities for the development of the rocket engine, which we are now engaged in, are being supplied by United.

Mr. DADDARIO. When you get to the 300,000-pound-thrust capacity which you have referred to, how far along are you in that program and how far away do you think you are from successfully concluding the research and development features?

Mr. COAR. I think any discussion of exact thrust sizes or progress on the schedule under our current contract would have to be considered classified, sir.

Mr. DADDARIO. We can take that up in the executive session.

How long ago did you start the research and development of this type of advanced stage?

Mr. COAR. The Advanced Research Project Agency announced the award of a contract for a high-energy upper stage rocket in the latter part of 1958; in October, I believe.

Mr. DADDARIO. That has been conducted almost exclusively at the Palm Beach facility?

Mr. COAR. The major portion of this work is conducted there; yes, sir. We draw also on our technical talent and the facilities in Connecticut as well.

Mr. DADDARIO. How many personnel are involved in this research and development process at Palm Beach, in this program alone?

Mr. COAR. The total technical personnel in our Florida research and development center as I mentioned earlier is something on the order of 350 people. On our upper stage rocket program, depending on the day's requirements, I think between one-half and one-third of our Florida personnel are actively engaged in this work.

We also draw as required upon our personnel and facilities available in Connecticut.

Mr. DADDARIO. That is all the questions I have. I think it is a very good statement you have made, Mr. Coar, and one which is easily understood.

The CHAIRMAN. I want to ask a question or two. You say "as far as hazards are concerned, we have found in many ways liquid hydrogen is less dangerous than gasoline."

You also say that it can be produced at reasonable cost. About what does it cost to produce a liquid hydrogen run in normal contracts with the Government?

Mr. COAR. We are not engaged in the production of liquid hydrogen. All of the fuel which we have used in our programs has been supplied by the Government.

The CHAIRMAN. You are producing the liquid hydrogen engines, aren't you?

Mr. COAR. Yes.

The CHAIRMAN. But the hydrogen itself is not produced by you?

Mr. COAR. That is correct.

The CHAIRMAN. But is found to be an acceptable fuel?

Mr. COAR. Yes.

The CHAIRMAN. In fact, it is a very valuable fuel, as you say in your statement. It has many attributes that other fuels don't have. But what does the cost normally run?

Mr. COAR. I think a quantitative answer to that would have to come from the Government agencies responsible for supplying the fuel.

The CHAIRMAN. Just approximately. We are not going to hold you to a figure.

Mr. COAR. It is my impression that it depends a lot on the rate, the size of the plant that is using it. But I think in all cases you would find that this figure ran between 10 cents as a minimum and a dollar as a maximum per pound. There is also the question in trying to establish these cost figures of whether you include amortization of plants and things like that. I think this gives you perhaps an idea of the order of magnitude, that is as close as I can estimate.

The CHAIRMAN. But as far as by the pound, it would run between those two figures you gave us roughly speaking?

Mr. COAR. That is my impression. I have no factual knowledge of the exact cost.

The CHAIRMAN. Is the engine which you are producing now in use in rockets?

Mr. COAR. This would be classified, sir.

The CHAIRMAN. All right, we will go into it in executive session. Any question from any members of the committee?

Mr. FULTON. I have some.

The CHAIRMAN. Mr. Fulton.

Mr. FULTON. Would you explain to us the use of helium in rockets and missiles, and how necessary that is?

Can you comment on that?

Mr. COAR. Helium has a particular application in conjunction with liquid hydrogen because it is the only element that does not freeze at liquid hydrogen temperatures.

Mr. FULTON. So actually it is the gas used with liquid hydrogen; is that not right?

Mr. COAR. It is used with other propellants. It is commonly used as an insert pressurizing medium because it is lightweight and inert and nonreactive as a purging agent or pressurizing agent.

Mr. FULTON. Specifically, on a liquid hydrogen engine you need helium, don't you?

Mr. COAR. Not necessarily. There are other ways of accomplishing the job.

Mr. FULTON. Are there other ways of accomplishing the job so that helium is really not necessary in the missile and rocket program, do you mean to infer?

Mr. COAR. I am not sure I understood the question, sir.

Mr. FULTON. Are you inferring or stating that helium is not necessary in the missile and rocket program? If you are, I am very greatly surprised.

Mr. COAR. No; I did not mean to imply that helium is not necessary.

Mr. FULTON. Isn't it in common use as an inert agent, that where there are low temperatures and especially in relation to a liquid fuel like hydrogen in upper stages?

Mr. COAR. Yes; it is in common use.

Mr. FULTON. It is therefore on the present setup of combustion chambers a necessity. Helium is now a necessity, is it not?

Mr. COAR. It is a necessity in conjunction with the complete system requirements; that is correct.

Mr. FULTON. From what source do you get your helium?

Mr. COAR. We are concerned only with the propulsion end of the machine, not with the complete system. Our requirements for helium are quite small, and the helium is furnished to us as one of the Government-furnished items.

Mr. FULTON. May I put in the record at this point a statement that helium is produced from certain wells within 250 miles of Amarillo, Tex., and these wells contain 99 percent of the free world's known recoverable supply of helium. This natural gas is now being pumped to metropolitan areas for use as fuel, and the helium content is thereby wasted to the atmosphere. There has been a suggestion made that there be 12 helium plants placed along these gas pipelines to extract the small percentage of helium before it leaves the fields.

I wish that the committee staff would look into this to see whether, first, helium is necessary as a security matter for the United States and its rocket program, and, secondly, whether it is a proper course to recommend that such 12 plants be set up along the pipelines near Amarillo, Tex.

That is all, thank you.

Mr. KARTH. Mr. Chairman, I have a question, please.

The CHAIRMAN. Mr. Karth.

Mr. KARTH. How much of an investment does your company have in research and development facilities in this rocket engine, rocket fuel field?

Mr. COAR. I don't know the answer to that question, sir.

Mr. KARTH. Could you provide that for the record?

Mr. COAR. I will request it.

Mr. KARTH. When you do, would you also provide for the record the amount of those dollars that are Government dollars and the amount of those dollars that are private—that is, invested by your company out of its profits in other fields.

I would like, if you can, to also supply to the record the amount of money invested in these facilities from profits in this field itself so we would have three breakdowns: That is, the direct Government outlay in dollars, the private investment dollars, and of these private investment dollars, those dollars that come about as a result of profits in this field since you have been in it with Government contracts.

Mr. COAR. You are speaking of investment in the field of propulsion facilities?

Mr. KARTH. For rocket engines; yes, sir.

Mr. COAR. For rocket engines only? I will request that information.

[Reports from United Aircraft are on file with the committee.]

Mr. FULTON. Mr. Chairman, could I finish with one other point. I would like to recommend the existing Helium Act of September 1, 1937, be amended to afford the Government access to all the Nation's helium reserves, including that which is part of the natural gas flowing through pipelines. I would like to ask the committee staff to look into that, if they would.

The CHAIRMAN. I am familiar with the act. I was talking to Mr. Teague from Texas. He and I both have a great deal of natural gas in our areas. If the staff will do it, it will be fine.

Mr. FULTON. Thank you very much.

The CHAIRMAN. Any further questions, Mr. Daddario?

Mr. DADDARIO. Mr. Coar, is there any possibility you may be able to develop this power so that it can be used at the booster level rather than just at the advanced stages that you are suggesting?

Mr. COAR. I think there is certainly that possibility. We are all aware that the expense in the development of a booster is quite immense. We have currently available well-developed boosters and others under development. I think it is a question of economics whether such a step should be taken.

There are further some technical problems involved in first-stage application of hydrogen because of its extremely low density. It results in a much larger volumetric package than with existing boosters.

Mr. DADDARIO. From an experimentation standpoint then, as you develop it through this stage, there is the possibility, is there not, that eventually you could transfer the knowledge that you have so that it could be adaptable to the booster stage as well?

Mr. COAR. Absolutely. There is no reason why this could not be done. It would have benefits. They would not be as significant—as overwhelming, perhaps I should say—as those we receive applying to the second or third stage.

Mr. DADDARIO. This would be an orderly process then as you take the experiments at this stage, develop them, get to the point where you are completely successful, and then use the knowledge and information which you have and adapt it to the other stages, including the booster?

Mr. COAR. This would be a straightforward, engineering approach.

Mr. DADDARIO. Somewhere along the line you mentioned the fact that this was a means through which you could more quickly get to the transportation of men through space, that it was safer than using fluorides for example. Why is that? What type of danger is there between the two types?

Mr. COAR. I think you are referring to the part of the statement which I did not present, which was concerned with the two ways of obtaining in chemical rockets the high specific impulse, highly efficient performance that hydrogen offers. One of these is to use liquid oxygen as the oxidizer and the other is to use liquid fluorine.

The advantages of fluorine are quite small. In most cases they are not significant. There may be a very few missions where it is worth the effort to go after this small advantage.

But our feeling is that this is a very small advantage and that when we are talking about a man-carrying vehicle, the extreme corrosive characteristics and toxicity associated with fluorine pretty much rule it out.

Mr. DADDARIO. And that therefore the hydrogen utilization does the job, takes away the dangers involved, and there is not such a margin of efficiency increase by using the other method.

Mr. COAR. This is liquid oxygen in conjunction with hydrogen; yes, sir.

Mr. DADDARIO. That is all, Mr. Chairman.

The CHAIRMAN. Thank you very much, Mr. Coar. We appreciate your testimony very much.

At this point the remainder of the witnesses are due to be heard in executive session. We have Dr. Arthur R. Krantrowitz, director of Avco Research Laboratory, vice president of Avco Manufacturing Co., of Everett, Mass.

We have Mr. Thomas F. Dixon. We have had Mr. Dixon before—chief engineer of Rocketdyne, North American Aviation, Inc., of California.

Mr. J. A. Reid, executive vice president and general manager of the Astrodyne, Inc., McGregor, Tex.

Dr. Robert I. Strough, project engineer, CANEL, United Aircraft Corp., Middletown, Conn.

And Dr. Harold W. Ritchey. We have had the pleasure of having Dr. Ritchey before, from the Thiokol Chemical Corp.

And Dr. Edward H. Seymour, director of research of the Thiokol Chemical Corp.

The committee now will go into executive session.

(Whereupon, at 10:35 a.m. the committee went into executive session.)

EXECUTIVE SESSION

The committee continued in executive session at 10:35 a.m., in room B-214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. Dr. Arthur R. Kantrowitz, of the Avco Manufacturing Co.

Doctor, you are the director of the laboratory. We are glad to have you here this morning. What you have to say is in executive session. We would be happy to have you just let your hair down and go ahead and tell us what you have got in mind.

STATEMENT OF DR. ARTHUR R. KANTROWITZ, DIRECTOR OF AVCO RESEARCH LABORATORY, VICE PRESIDENT OF AVCO MANUFACTURING CO.

Dr. KANTROWITZ. Thank you, Mr. Chairman. I appreciate the privilege of this opportunity to appear. In coming before this committee, the major point I wish to make is to give you my impression of what can be done to accelerate our progress in space activities.

The first point that I would like to make is to consider what takes time in any bold, new experimental program. We hear many statements about how many years will be required to do this, that, and the other thing. I think it should be emphasized over and over again that most of the time required is spent not in doing the job involved, but in obtaining the decision to go ahead and do it.

This has been true of most any of the important projects that you can think of that have been proved important in the past. In technology, most of the basic science which is required has been around for many years. The knowledge required to construct large rocket vehicles has been here for at least 50 years. The thing that has been missing, and the reason we didn't explore space a long time ago, has to do with the decision to do it. This is true of the venture as a whole, and it is also true of many of the smaller tasks, such as various satellite programs we have set out to do.

Yesterday you heard a great deal about electrical propulsion. I think I have very little to add except to say I agree that electrical propulsion will produce very substantial gains in what you can do with a given booster. You can save something like a factor of

three on missions that are as far as the moon, say, and larger factors, if you go further.

What do we need to make electrical propulsion a reality? Essentially, what we need is just the decision that this country will try real hard to achieve electrical propulsion so that these great savings in cost can be realized. The art that is needed in order to accelerate gases electrically, the scientific basis, I think we already have. What we need is to get busy and try and do that job.

The Avco Research Laboratory has been fortunate in getting the approval of ARPA and the Office of Scientific Research of the Air Force for such a job now.

I would like to say, however, that this research program could have been undertaken some time ago if the decision had then been made. I believe it is important for the Congress to be fully aware of the fact that exploratory research has not changed very much from the time of Columbus. In his case it took him 10 years to get a decision, and 5½ months to gather a fleet and discover the New World.

That situation is not much different now than it was then—that you may need many years to get a decision and months to do a job.

I would like to say that typical of the kind of thing that this country can do is in my opinion represented by the ICBM program. Here when a decision was finally made in 1954, the country assembled resources starting mostly from people who were engaged in entirely different fields, but who had the required scientific background. After the decision was made, there was created a tremendous sense of urgency and all the obstacles fell by the way. Once the sense of urgency has been created and the decision made, I think that this country is capable of very rapid motion.

When people tell you so many years are required before a job can be done, I think that it would be very well to cross-examine them and find out what is going to be done in all those years and what are we doing now and what is holding up progress.

In many cases I believe you will find that what is holding the thing up is the lack of people courageous enough to make the decision that must be made and to take the responsibility for committing major resources to an adventurous program.

Thank you very much.

The CHAIRMAN. What would it take, Doctor, in the way of resources to do the job?

Dr. KANTROWITZ. To do which job?

The CHAIRMAN. Suppose you feel you created a sense of urgency and you make the decision, what will it take in the way of resources? Is there any way to know in advance?

Dr. KANTROWITZ. The only research program of this kind in which I have been involved in great detail in trying to get decisions has been the task of putting a man in space, and recovering him safely.

The CHAIRMAN. I was referring to the job of devising electrical propulsion.

Dr. KANTROWITZ. That one I can talk about too. We have been engaged for some time in fundamental research that is related both to propulsion techniques and the electrical properties of gases at

high temperatures. We are presently negotiating a contract with the Office of Scientific Research, and with ARPA.

The objective of this program is to make possible a decision, to make it possible for space program planners to more safely commit themselves to planning major space projects for this Nation which could depend on electrical propulsion.

So far as I know, none of the plans for major programs that we have now depend on the real advantages of electrical propulsion. For example, in the case of the communications satellite program, which is a matter of very great importance in my opinion, propulsion is based on chemical rockets alone.

If I had to make such plans at this time, I would also make them on chemical rockets. But if this program could safely be based on electrical propulsion, you would save something like a factor of two or three in the cost of launchings. In order to have reliable electrical propulsion systems in 2–3 years, all elements of those systems should be given intensive research and development support now.

Mr. FULTON. May I compliment you on your statement on the communications satellite, and secondly, on the electrical propulsion compared with chemical propulsion methods.

The CHAIRMAN. Mr. Teague.

Mr. TEAGUE. Doctor, I am sure you know Dean Dunning of Columbia?

Dr. KANTROWITZ. Yes, sir. I was a student of his at one time.

Mr. TEAGUE. Five years ago, sitting up at West Point one night in the Thayer Hotel, I heard Dean Dunning for no apparent reason start discussing this whole space business. He described just about exactly what has happened to date. He talked then about how we were dragging our feet in different fields.

The other day I asked Mr. Hoffman some questions here thinking along that same line—are we dragging our feet now? If we are going to need a 10-million-pound-thrust engine and we are working on a million and a half, are we dragging our feet?

I wasn't trying to get in the Bureau of the Budget battle. I was strictly talking about the other side of it. Are we dragging our feet? Do we let a company have a contract on a million and a half when actually they should be working on a 5, 6, or 10 million?

Dr. KANTROWITZ. Could I put it this way, perhaps: I would feel better about our space program if I saw us making more mistakes than we do. We have been so cautious that on the whole we don't make as many mistakes as I would like to see us make in order to make maximum progress.

Mr. TEAGUE. We are too conservative?

Dr. KANTROWITZ. Yes; we review and check so much and are so reluctant to stick our necks out that I believe we are making much less progress than is possible—and vital to our position vis-a-vis the U.S.S.R.

One very great exception to our overcautious attitude has been the ICBM program. When this program was started in 1954, the Department of Defense, the Air Force, and industry had their necks out. It was way, way beyond what had been done. Nevertheless, a major commitment was made, on the order of billions of dollars. This was real courage, and it is this kind of courage that is really needed over

and over again, and on a larger scale, if this country is going to compete in the "space race."

Mr. BASS. Would you yield?

Mr. TEAGUE. Yes.

Mr. BASS. I appreciate what you say, Doctor, but it seems to me this whole field is a matter of balance and judgment. You can err too much in the other direction, which would be disastrous.

Dr. KANTROWITZ. To be sure.

Mr. BASS. For instance, to take your example of this plan for sending up a communications satellite. If we based it on an electrical propulsion system, might it not be possible that that project could be delayed for several years because of the lag in perfecting such a system?

Dr. KANTROWITZ. If I had that decision to make at the present moment, my tendency would be the following: that I would have a program that would be based on chemical propulsion that I could count on, and I would have not one approach such as we have, but would have a substantial expenditure in development of electrical propulsion spread over many contractors, to try and make possible an electrical system which could be depended upon before I had committed or expended the major production funds on the chemical one.

Mr. BASS. Even though we are very, very early in the research and development stage.

Dr. KANTROWITZ. Yes. Let's take a chance. Let's accept the risk—we stand to gain very great benefits if successful. Let's have the courage to risk making a mistake.

Mr. BASS. The problem as I see it, overall, is that we have only so much talent in this field, and just spending money doesn't necessarily solve the problem. It is where our effort should be focused. Is that not correct? We can't go all-out in every direction.

Dr. KANTROWITZ: To be sure you cannot. You can find, however, that there are a really limited number of genuine new ideas and concepts that we have. The really great question is how well we do nurture these ideas. How fertile a soil do we provide so that it is easy for them to grow.

You will find that if the ideas depend for their fruition upon the materials and resources that a man can easily assemble without anyone else having to stick their neck out, that those ideas will progress rapidly. If someone else other than the father of the idea has to stick his neck out, then it moves much more slowly. As this chain is further removed from the father of an idea, then the time scale stretches out into the distant future.

This is how we get these longtime estimates of why it takes such a long time to get anything done.

Mr. TEAGUE. One other question, Doctor, and I will quit, along the same line Mr. Bass talked about. Is our scientific ability of this country properly directed, or is it spread all over the field, going in every direction?

Dr. KANTROWITZ. I think, if anything, that there is an emphasis on too much direction, you must remember that when science progresses rapidly, there is usually no other organization except what Jefferson once called the free marketplace of ideas. The persons responsible for research programs decide what to work on by themselves, looking at

the whole scientific community, going to scientific meetings, reading the literature, and finding what other people are doing by themselves, making the decision for themselves, what they will work on.

This is the way that science has flowered, without any overall organization of any kind. We must find some way of duplicating the power of that free marketplace of ideas, at the same time making available the larger scale resources which are necessary for such things as space.

The CHAIRMAN. May I ask you this, Doctor: I rather agree we are too cautious. I think we are too cautious in the * * * program. Are you familiar with that?

Dr. KANTROWITZ. * * *
Mr. FULTON. * * *
The CHAIRMAN. * * *
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Mr. FULTON. * * *

The CHAIRMAN. I want to ask him another question, then I will recognize the gentleman to ask questions.

I want to ask him this, though, in reference to the electric engine. If it is developed as such and you feel that we ought to stick our neck

out and develop it, would it be usable for any commercial activity or any other activity, say, for outer space and perhaps deep probes?

Dr. KANTROWITZ. I would say this, that the one commercial activity that I see at the moment is the communications satellite. It is my opinion that the communications satellite will be such a valuable thing as to pay entirely for our space adventures.

For the communications satellite, electrical propulsion will effect a cost saving of the order of a factor of 3. To that extent it is a very fine commercial venture. I only wish that this country were so organized that something like the communications satellite would be a feasible thing to be undertaken by private industry alone. But that is, I think, almost out of the question.

The CHAIRMAN. But you see now no possibility that the principles used in the development of that electric energy would be adaptable in any way to commercial use?

Dr. KANTROWITZ. There are all kinds of commercial possibilities that are closely related. For example, we have been engaged in discussions with several of the large public utilities on the possibility of the generation of electrical power directly from the motion of an ionized gas.

You generate an ionized gas, say, by passing a gas through a nuclear pile, and then pass that gas through a magnetic field and generate electricity thereby.

This seems to be an important practical possibility for the cheaper generation of electrical power, both from nuclear and from chemical fuels. That work is very closely related to the work that we are doing in electrical propulsion, related in the same manner as an ordinary electrical generator is related to an electric motor.

As you know, they look practically alike, and they are nearly alike. Now, because of our background in that commercial work in the generation of electric power, we had an advantage, in our recent propulsion proposal to ARPA. I think this was a significant advantage in our gaining this contract.

The CHAIRMAN. Mr. Fulton.

Mr. FULTON. May I congratulate you on your statement and likewise thank you for coming here. You are one of the outstanding people in this field and your advice, I believe, will be well considered by this committee and the Congress. * * *

Dr. KANTROWITZ. * * *

Mr. FULTON. Then your position is that we should proceed on the research and development of various systems such as the Nike-Zeus, A–ICBM system, as well as, say, several that the Navy have and other agencies of the Government so that we have a broad base of research on this point.

Dr. KANTROWITZ. To be sure, and competitive research.

Mr. FULTON. That is what I agree with.

Dr. KANTROWITZ. Competition in research is most healthy.

Mr. FULTON. As a matter of fact, on the awarding of the man-in-space program to McDonnell Aircraft, I had felt it was much better to have the 37 companies who were interested in it proceed along the development of their particular type of recommendations to a certain point where, as we went along, we could see whether there was gain to be gotten from that type of a program before we just dropped them all and settled on one under McDonnell Aircraft.

Mine would be the pyramid approach, a broad base with competitive research and development among various companies. Would you agree with that?

Dr. KANTROWITZ. I think that that is an eloquent statement of how things ought to be done.

Mr. FULTON. I appreciate that. But I thought you gave a very eloquent one, and I am going to ask you if you will say this to me publicly.

Mr. Teague had asked: Are we dragging our feet in the space program? You had said—and I would like you to say that this is not secret—"I would feel better about our space program if I saw us making more mistakes."

The CHAIRMAN. Wait just a moment. I am afraid of this—I have no objection to your making it. But I am afraid if we begin to let out certain parts of this as against other parts, we are going to get ourselves tangled up.

If the witness makes one statement that is open for publication and the next statement that is secret here in this executive session, we are going to get into trouble.

Dr. KANTROWITZ. * * *

Mr. FULTON. I have only had 3 minutes, so I would like to——

The CHAIRMAN. I want to say this now. I am not trying to push anybody. We have Mr. Dixon and Mr. Reid and Dr. Strough and Dr. Ritchey and Dr. Seymour all before noon. They come from distant points, all of them. I just want to let the committee know it.

Mr. BASS. Mr. Chairman, I hope we can hear these gentlemen. We only have 50 minutes.

Mr. FULTON. I want to give notice I am going to ask the witness this outside to repeat it, and I think the chairman should hear it because I am going to ask you to repeat this to me outside.

The CHAIRMAN. You don't have to give notice in the committee. You are free, white, and 21. You can do what you want on the outside of the committee, and so can the witness.

Mr. FULTON. With the Chairman's permission I would like to read this to you and check it: "And it has cost us a great deal. One exception is the ICBM program. A major commitment was made in 1954. We stuck our necks out in developing ICBM. It was real courage." * * *

Dr. KANTROWITZ. * * *

The CHAIRMAN. What occurs and what is said here is executive. What he does on the outside is his business there. I do expect, and I think everybody on the committee expects, every member of the committee to retain in executive session what is said and what is done here in this committee.

I think there can be no exceptions on that.

Mr. FULTON. That is right, Mr. Chairman. But I want to make sure that there is no classified material——

Dr. KANTROWITZ. * * *

Mr. FULTON. All right, then I will not do that, of course.

The CHAIRMAN. Any further questions? If not, it is 11:15 here and we had better proceed to hear these other witnesses.

Mr. KARTH. Mr. Chairman, I would like to ask the Doctor a question, please.

The CHAIRMAN. Surely.

Mr. KARTH. I think probably there is something wrong with our system here. We really don't have enough opportunity to ask questions, rather than——

Mr. BASS. We haven't had any.

Mr. KARTH. Rather than—oh, shall we say, making our interrogation a soft interrogation rather than a hard one. There just aren't enough hours in a day, it seems. I am sure that you appreciate that, Doctor.

One thing that comes to mind, and often has, so far as I am concerned, is we are talking about courage. There is a little too much profit courage in some areas rather than enough patriotism courage.

This, I suppose, you find in any country, including our democracy. You suggested that we be a little sharp in our interrogation. I would like to do that, if you don't mind.

Dr. KANTROWITZ. To be sure.

Mr. KARTH. When you are talking about courage, you are really talking about money, aren't you? When you are talking about going ahead, you are talking about speeding up our program. When you are talking about doing these things at a more rapid pace, aren't you talking about money, Doctor?

Dr. KANTROWITZ. It will take money.

Mr. KARTH. Do you think it will take more money than has been requested, sir, for this program?

Mr. BASS. Which program?

Dr. KANTROWITZ. Which program are you talking about?

Mr. KARTH. The space program that is in the budget.

Dr. KANTROWITZ. There is little doubt in my mind that the occasional really great idea would have a somewhat easier time growing if budget restrictions were not too strenuous. On the other hand, we would risk the waste of more money.

Mr. KARTH. But in your analysis of this thing, Doctor, it seemed to me you indicated that, although we might waste some money, the courageous thing to do was to make those decisions and go ahead and see if we can't reach our ultimate goal, despite the fact that we might waste some money.

Is this an accurate statement?

Dr. KANTROWITZ. Right. I would like to talk to some extent to the thing you call "profit courage."

Mr. KARTH. The thing I was talking about is exactly what Mr. Teague was talking about. We go ahead and we develop a 100,000-pound thrust engine. We have got to perfect that thing before we go to a 150,000; and when you perfect that, we go to a 300,000 and so on up the line.

Mr. Teague's point was very excellent when he said, "Don't you think we should get some courage along this line? Instead of jumping by 50,000-pound thrusts, why don't we jump 5 million for a change and see what we can do with that?"

So I say there is a great deal of waste of money in this area which I think Mr. Teague expressed very well, which we could eliminate by going from the 100,000-pound thrust to the 1 million, or some other figures.

I am picking these figures, but we are moving very slowly in my opinion in this field. This is the profit courage that I was talking to you about.

Dr. KANTROWITZ. I am not exactly sure on simple technical grounds that bigger and better rockets are always necessary and desirable. For example in many space missions the use of electrical propulsion may permit the doubling or tripling of your payloads, using the same booster rocket. I would like to call to mind, though, another example of such courage. During the war when reactors were very new in the early forties, enough courage was exercised there to commit the country to the Hanford plant with enormous reactors on the basis of timely experiments. This was another example of tremendous courage, because that whole thing could have been made to look very foolish had it failed.

It is that kind of thing that will make it possible for this country to keep up. If we don't do that, if we play it safe, we are going to lose. I am sure of that.

Mr. KARTH. Let me ask you this question, Doctor. The chairman was talking about the Nike-Zeus. I am not necessarily saying I am for the Nike-Zeus program. But if we are talking about courage, I suppose we should take a look at the defense system because we all agree we don't have one against ICBM's.

It seems to me if we went ahead with this project we might in the opinion of some be showing courage to at least try to develop an antimissile system. For those who think we should have courage but still recommend that we don't go ahead, they must have a better system in mind.

What is your system? We are in executive session. Do you have a better system?

Dr. KANTROWITZ. * * *

Mr. KARTH. You see, on this thrust thing, we started out with a very low thrust ratio. Now we are talking about 6 million pounds of thrust. We had to start someplace.

My question is: Do you think that we shouldn't start with any defense system until all of a sudden a perfect one springs up out of the air? Or what is your opinion?

Dr. KANTROWITZ. * * *

Mr. KARTH. * * *

Dr. KANTROWITZ. * * *

Mr. KARTH. We have that right now in our ICBM field, don't we? We couldn't hit New York, probably, if we tried.

Mr. FULTON. Neither could the Russians.

Mr. KARTH. This is kind of a false sense of security, isn't it, even at this point in the whole ICBM field? Can you throw some light on this thing as to our potential strength in the ICBM field? Don't misunderstand me; I am not being derogatory, Doctor. I am trying to follow what you suggested.

Dr. KANTROWITZ. * * *

Mr. BASS. Mr. Chairman, I hate to interrupt, but we have five other witnesses.

The CHAIRMAN. That's right. I am perfectly willing, I will say to the committee now, to meet tomorrow morning, Saturday morning. If we can't see these witnesses today—and we do have votes coming up this afternoon so we can't meet this afternoon——

Mr. FULTON. May I say to the chairman that we in the Foreign Affairs Committee have been meeting in the afternoons and have

just been leaving to go to votes and coming back. So I think we could go right straight through.

I would love to go through this afternoon.

Mr. KARTH. I am willing to come tomorrow morning, Mr. Chairman.

The CHAIRMAN. We are going to probably have a vote the first thing, or pretty close to the first thing. I can't see where you make any profit by trying to meet——

Mr. FULTON. The word is there won't be a regular vote because I was in on the debate yesterday.

Mr. QUIGLEY. Mr. Chairman, while this colloquy is going on, may I ask the Doctor one question? He says if we play it safe we are going to lose.

Aren't we playing it too safe in the whole space program?

Dr. KANTROWITZ. I would say so.

The CHAIRMAN. Thank you very much, Doctor.

Mr. TEAGUE. Doctor, if the Russians put a manned satellite up this year, how much would it accelerate our program?

Dr. KANTROWITZ. * * *

The CHAIRMAN. Thank you very much, Doctor.

Mr. FULTON. I must have an answer explained, Mr. Chairman.

The CHAIRMAN. We are going to call——

Mr. FULTON. Mr. Chairman, I can't go ahead without the last answer being explained. I must have that explained. Would you please yield to me so that it can be explained, because I have listened for 12 minutes now and I was called before I had had 5.

The CHAIRMAN. You haven't listened any longer than the others on the committee have listened.

Mr. FULTON. I know; but there have been 12 minutes taken and I want 1 more minute.

The CHAIRMAN. All right, go ahead now. I want to be courteous to the gentleman and I am going to do all I can——

Mr. FULTON. I will be very short but I need one answer explained, and it is a very serious question.

The CHAIRMAN. Go ahead, sir.

Mr. FULTON. May I first compliment the gentleman from Minnesota, Mr. Karth. He has made one of the best statements——

The CHAIRMAN. Does the gentleman want the witness to answer or does he not want the witness to answer?

Mr. FULTON. I do; but I want to make a slight compliment in 10 words. I don't want it all on one side—the time on one side—and the others cut short by 10 words. If the Chairman will permit me to have 1 minute, which I have asked for, 1 minute, we will get along much better or else we are going to have a system of dividing the time and taking 5 minutes for each person.

The CHAIRMAN. I think that is a good idea.

Mr. FULTON. Let's do it. I have asked for 1 minute——

The CHAIRMAN. The Chair will work out a system of dividing the time in the future.

Mr. FULTON. I certainly think that is the better way.

The CHAIRMAN. Go ahead. The gentleman has already taken more than a minute, but go right ahead.

Mr. FULTON. I haven't had a chance. I don't want you to give the impression—I don't believe you intended to—that our space program is not, in the United States and in the free world, a good program; and that it is progressing rapidly and with every indication of success, not only for the scientific value but also for the security in the protection of the United States of America and the free world.

Would you comment on that, please?

Dr. KANTROWITZ. * * *.

Mr. FULTON. * * *.

Dr. KANTROWITZ. * * *.

The CHAIRMAN. Thank you very much.

Mr. FULTON. May I just finish with this: You do have confidence in our current space program, do you not, and our missile and rocket programs, that we are making progress—

Dr. KANTROWITZ. * * *.

Mr. FULTON. Thank you very much.

The CHAIRMAN. Thank you very much. Dr. Sheldon, will you see the other witnesses we have this morning and find out how many of them can meet with us tomorrow morning. We will continue as long as we can today, and those that we don't hear today, then we will meet tomorrow morning. I hope everybody can come.

Mr. TEAGUE. Mr. Chairman, I think Mr. Fulton's suggestion is an excellent one. Give each person a certain amount of time for each witness, and let it go all around.

The CHAIRMAN. The Chair is going to appoint one member from the Democratic side and one from the Republican side to work out a system of handling the time, and we will abide by——

Mr. FULTON. Just make it a 5-minute rule for each member.

The CHAIRMAN. I want to appoint a committee so it will be completely bipartisan. We will work out a rule so there will be an equitable distribution of time. Especially it is important when we have this many witnesses as we have this morning.

Mr. BASS. While we are waiting, Mr. Chairman, it is my understanding that in these executive sessions we observe them as such, and we don't make releases based on what has been said.

The CHAIRMAN. That is certainly the rule of the House of Representatives.

Mr. DADDARIO. Mr. Chairman, I would like to suggest we hear each of these witnesses completely through, one after the other; and then call back those which we feel we have questions to ask of. We may be missing the boat on the third or fourth one, who may have something more important even than this one.

The CHAIRMAN. Is there any objection to that procedure? If not, we will hear each one without any questions, and then we will call back the ones that we have questions of.

We have Mr. Thomas F. Dixon and Mr. J. A. Reid.

Mr. HOFFMAN. Mr Chairman, I am Samuel Hoffman, vice president and general manager of Rocketdyne. I will read our prepared statement, if you will permit me to. I would like to have Mr. Dixon at the table with me, and Mr. Reid.

STATEMENT OF SAMUEL K. HOFFMAN, VICE PRESIDENT, NORTH AMERICAN AVIATION, INC., GENERAL MANAGER, ROCKETDYNE DIVISION; ACCOMPANIED BY THOMAS F. DIXON, CHIEF ENGINEER, ROCKETDYNE; AND J. A. REID, EXECUTIVE VICE PRESIDENT AND GENERAL MANAGER, ASTRODYNE, INC.

Mr. HOFFMAN. Information on active space propulsion projects underway at the Rocketdyne Division of North American Aviation, which could not properly be presented in the open sessions of the Science and Astronautics Committee, is summarized in these notes.

1. * * * The complete 1.5-million-pound engine is in process of design.

2. * * *

3. * * *

4. * * *

5. * * *

6. In connection with the Rover program (nuclear rocket), Rocketdyne has supplied the test nozzles for the LASL series of Kiwi-A tests. * * *

7. The ion engine work was rather completely covered in the open session. The current program covers the development of an experimental low thrust ion propulsion device, the equivalent of a thrust chamber.

Questions and answers during the open sessions lead us to conclude with the following generalized statements:

(*a*) All three types of rocket engines, chemical, nuclear, and electric, will be required for an indefinite period of time. Each has its major field of application, substantially as follows:

Chemical: Terrestrial missions; first-stage boosters; high energy, upper stage engines.

Nuclear: Upper stages as soon as available; eventually as the booster for very large payload vehicles.

Electrical (ion, plasma, etc.): A space engine—for maneuver and endurance; worthless as booster powerplants.

(*b*) The major influence on countdown time is the mission, whether an R. & D. test, a satellite launching, or a moon shot. The influence of the engine on countdown is related only to the fueling operation, and even if the fuel is not stored aboard the missile, the fueling operation, with proper equipment, is measured in minutes.

Whether solid or liquid, the propellant can be aboard continuously. With cryogenic propellants (such as the current LOX–RP), auxiliary equipment is required for the propellant to be aboard continuously. No auxiliary equipment is required in the case of storable liquids or solids; hence, the "instant readiness" feature is essentially inherent with these types of propellants. The time required for launch now becomes one associated with guidance, auxiliary power, and other associated equipment.

(*c*) The hard-site concept is applicable regardless of propellants used: solid, liquid, storable or not.

(*d*) There was considerable discussion on basic research and where it should be done. All of the comments centered around the propellant. Of at least equal importance, particularly in the case of solids, is research on materials, both metals and plastic.

Basic research on propellants, metals and plastics should be done in the respective primary industries. However, concurrent research in these fields is essential in the rocket engine organizations. In these organizations, a major portion of the effort would be testing the feasibility of developments as applied to the particular application at hand.

Finally, we must not overlook the fact that concurrent research on the engine systems and components within the rocket engine industry is equally imperative.

Approximately one year ago Phillips Petroleum and North American Aviation set up a jointly owned corporation, Astrodyne, to apply the resources and talents of the respective organizations to the development of solid-propellant rocket engines.

Mr. James Reid, vice president and general manager of Astrodyne, is with us today. We request the opportunity for Mr. Reid to present a unique continuous mix process which is now under development.

The CHAIRMAN. Thank you very much, sir. Did you say Mr. Reid had a statement, too?

Mr. HOFFMAN. Mr. Reid.

Mr. REID. Gentlemen, I have a statement which has been turned over to Dr. Sheldon. In the interests of conserving your time, I would like to highlight it very briefly, however.

The CHAIRMAN. We have agreed on this, I might say—to hear all of the witnesses; then those that we wish to question at length, we will try to arrange to meet later on, perhaps in the morning, to question them.

Mr. REID. Astrodyne is active in a broad range of research looking forward to the application of the large solid, high-energy propellant systems to large missiles and rockets, and specialized energy uses.

* * * * * * *

The CHAIRMAN. Thank you very much, sir. Are there any other statements from North American? If not, we want to thank you gentlemen. Do we want to ask these gentlemen to stay over for questioning? I don't know whether they are able to or not. If they are not able to stay over for questioning, we will ask them to wait, if they will, until we can hear the other witnesses and then call them back for questioning.

Dr. SHELDON. Sir, they have a 1 o'clock plane which they are trying to catch.

The CHAIRMAN. Then we want to thank you gentlemen very much for coming here.

Dr. SHELDON. Apparently they are willing to change their plans for the convenience of the committee.

The CHAIRMAN. We want to thank you very much. We are just in a jam on time here. We may get into a bunch of votes this afternoon. On the other hand, we may be able to go until 1 o'clock. If they would be willing to stay, for instance, until the last moment that they have to leave here to catch their plane, it would be fine. Then we might need them.

Thank you very much, gentlemen.

Dr. Strough. Dr. Strough, whenever you are ready to proceed, we are ready to hear from you.

STATEMENT OF DR. ROBERT I. STROUGH, PROJECT ENGINEER, CANEL, UNITED AIRCRAFT CORP.

Dr. STROUGH. * * *
The CHAIRMAN. * * *
Dr. SHELDON. * * *
Dr. STROUGH. * * *

The CHAIRMAN. Thank you very much, Doctor. Do you have a statement, sir? Is there any other statement from your group?

If not, we want to thank you very much for these statements. What we are trying to do is to hear every witness, because we are in a little jam today. Then, if we have time, we want to question those later on, if we may. So we thank you very much.

We would like to hear from Dr. Ritchey and Dr. Seymour, both with Thiokol Chemical. Dr. Ritchey and Dr. Seymour, the House is in session now, so I would suggest this, that you proceed with your statements, gentlemen, with dispatch, but we want to hear everything you have to tell us.

STATEMENT OF DR. HAROLD W. RITCHEY, VICE PRESIDENT AND TECHNICAL DIRECTOR, ROCKET DIVISIONS, THIOKOL CHEMICAL CORP.; ACCOMPANIED BY DR. EDWARD H. SEYMOUR, DIRECTOR OF RESEARCH, REACTION MOTORS DIVISION, THIOKOL CHEMICAL CORP.

Dr. RITCHEY. We did not prepare any formal statement this morning. It was our understanding that it was principally the objective of the committee here in this day's session to ask us questions involving areas of security where we were not able to give complete answers in the open testimony.

The CHAIRMAN. Do you have anything to add in the way of a general statement, either one of you, to what you have already told us in open session? If so, I would suggest that you proceed with your general statements, whatever you may have.

Dr. RITCHEY. We have prepared some material here that does outline the specific impulse, or—if you please—the energy content of various types of chemical fuels, which we feel sets up the more or less maximum attainable goals by future research in the chemical propulsion field. We have tried to put this in the right perspective of other forms of propulsion such as nuclear.

I believe that the document is probably a little bit too lengthy to go into in detail here. I could summarize it for you, if you would care to have me.

The CHAIRMAN. All right, sir, if you will.

Dr. RITCHEY. This document, since it does name some numbers that fall into possible areas of security classification, is classified "Confidential." Although it is printed up, we do not have the proper stamps on it and will not be able to pass it out this morning.

We will try to get it to you as early as we can because it does have to be stamped on each sheet in order to meet the security requirements.

The other document is not classified and also contains some information here that might constitute future goals.

For example, in our present liquid propellent engines, with liquid oxygen and jet fuels, at the operating pressure of the engine at sea level, 266 pound-seconds per pound is mentioned here as an acceptable or achievable energy content.

With liquid hydrogen and liquid oxygen, this figure could be raised to above 360. We have a figure here of 364.

With the storable liquid engines such as hydrazine and nitrogen tetraoxide storable propellants, we should be able to achieve figures of over 265 pound-seconds per pound, and the ultimate achievable in the chemical systems we believe is that attainable by liquid hydrogen and liquid fluorine which calculates to be 374 pound-seconds per pound.

* * * * * * *

There should be aggressive research directed in these fields to improve the specific impulse of the fuels, both solid and liquid. The other areas involve what is known as free radicals. If this could be made successful, perhaps these numbers could be brought above the numbers that I have quoted.

In fact, theoretically there are some free radical fuels. If they could be stabilized, that could give specific impulses as high as 1,500 pound-seconds per pound.

Mr. FULTON. Is that in the oxygen field?

Dr. RITCHEY. If monatomic hydrogen could be stabilized and you could use a mixture of monatomic hydrogen and diatomic hydrogen in stabilized form and let it react to form very hot diatomic hydrogen in the rocket engine combustion chamber, you can potentially get specific impulses up around 1,500.

Mr. FULTON. I was really asking about the same in oxygen. Is there any research on that?

Dr. RITCHEY. * * *

Mr. FULTON. * * *

Dr. RITCHEY. * * *

Mr. FULTON. * * *

Dr. RITCHEY. * * *

Mr. FULTON. * * *

Dr. RITCHEY. * * *

Mr. FULTON. So you would then recommend to the committee—Mr. McDonough and I have done some work on this—that we do recommend such a program to the Congress so that if it is authorized, it could be proceeded upon immediately on a small scale as you suggest?

Dr. RITCHEY. I am not certain that some programs along this line are not at this point in being in the ARPA programs that have been let with the various chemical companies.

I am not intimately familiar with the objectives of the programs that were started last September with the five chemical companies that ARPA contracted with. It may be there is some work being done here in the field discussed.

Mr. FULTON. I know in the hydrogen field there is the RICA as well as the Phillips Petroleum type of research on that. But I have not heard of any of the type we are discussing.

Thank you.

Dr. RITCHEY. * * *

Mr. FULTON. * * *

Dr. RITCHEY. * * *

Mr. FULTON. With the chairman's permission, could I request that the witness supply for us his recommendation on a broad scale in the high polymer research field. I would like to have you comment across the field as to what we might be doing.

Dr. RITCHEY. In the high polymer field?

Mr. FULTON. Right.

The CHAIRMAN. Would you want to supply that for the record?

Mr. FULTON. Later; not now.

Dr. RITCHEY. I will be very happy to do that.

The CHAIRMAN. We want you, if you will, to proceed with your statement, if you have anything further.

Dr. RITCHEY. I believe, in view of the fact that this material is printed up and is essentially in written form here, that there is no need to continue with the prepared statement.

I have roughly abstracted what is in this. I wonder if Dr. Seymour would care to make any comments?

The CHAIRMAN. Dr. Seymour, we would be glad to hear from you.

Dr. SEYMOUR. The particular comment that I would like to make would be toward the difference in the limits which exist in trying to plan and accelerate our future progress as imposed by basic research effort and ability, and our applied research or engineering development ability.

We need both. Basic research tells us what Nature has given us; and it has become very obvious, I think, during the discussions of the last few days, that we need to exert every effort to find out the ultimate that can be done in storing energy and materials and finding materials for construction at extreme temperatures and many other factors.

Then we need to translate this into useful art. In some areas, as in maximizing propellant energy which Dr. Ritchey has just discussed, basic research is an extremely important forerunner. In others, as in the liquid systems where we have liquid hydrogen, liquid fluorine available, we need to develop the art to use them successfully.

The art can never give us a capability beyond what the basic research scientist has found out, but the applied scientist and engineer practicing the art and improving it can try to approach the limit established by the basic scientist.

One other point which I would like to add is that basic research in this, as in all fields, will flow into the industry from many quarters. We cannot expect to supply all our own basic research nor should we try. Much of it is better done in academic atmospheres of universities, governmental institutes, industrial institutes, and so on. We depend on this input from a very broad area of activity.

Another point is, too, that all of this progress represents a continuum. None of these efforts, whether we talk about the large liquid rocket, the nuclear rocket, the ion rocket, is something that we will start work on today, work harder on tomorrow and finish the day after tomorrow, figuratively speaking.

The whole progress in this area as in all man's areas of interest is a continuing stream. We don't know what's ahead. We have to look at what we think we can do, how badly we want to do it, and the degree to which we wish to assign our resources to the effort.

Thank you very much, sir.

The CHAIRMAN. Thank you, Doctor, and thank you, Dr. Ritchey. The whole thing, then, is just how badly we wish to accomplish a job and how much money we are willing to assign to that job.

Dr. SEYMOUR. Yes, sir.

The CHAIRMAN. What would you put as your No. 1 priority in this program?

Dr. RITCHEY. If you look at, say, the problem of pushing back the frontiers of knowledge rather than applied research fields, I feel the No. 1 priority in the chemical fuel problem is to explore some of these new compounds, putting materials together, elements together, that form the new compounds that have not previously been made, that can be stabilized in a form proper for use in either liquid or solid propellant rockets.

* * * * * * *

Mr. FULTON. One of those combinations might be the helium-hydrogen combination.

Dr. RITCHEY. The helium-hydrogen combination—there are two possibilities there. One of them, of course, is the possibility of carrying out a nuclear fusion reaction. Of course, if we could learn to do that effectively, we would travel through space in comfort. It takes only a few pounds of rocket propellant per ton of takeoff weight to achieve escape velocity, land on the moon, and come back again, if you can make those kinds of fuels fully effective.

Mr. FULTON. Already it is going on in the sun under extreme temperatures, changing four hydrogen to one helium.

Dr. RITCHEY. There is some work being done in this country of course along this line. This is covered under the technology or disciplines called magnetohydrodynamics. People are trying to contain extremely hot materials in magnetic and electric fields rather than trying to contain them with actual structural components.

This, of course, is the only way we can foresee to handle materials that are this hot—which is temperatures in the order of 10 million degrees centigrade. I am sorry, I meant to say 100 million degrees centigrade. I said 10.

The CHAIRMAN. That is far ahead, isn't it?

Dr. RITCHEY. It is far ahead. We can achieve these things only by pursuing work aggressively in a laboratory.

Mr. FULTON. But not so far ahead we shouldn't be trying for it because actually it is a nuclear type of evolution. When it is occurring one place, possibly we might in much smaller degree achieve it through nuclear plus acceleration or a combination of these metals.

Dr. RITCHEY. I agree with you completely, and the fact you can see this going on in any clear day when you look up in the sky really whets your curiosity because you know it can be done. All we have to do is get smart enough to do the same thing on earth.

Mr. FULTON. I am certainly glad you are here. You are encouraging. Some of us get pretty far out in space.

The CHAIRMAN. These are the last witnesses. Are there any further questions? If not, these gentlemen have a plane—you have a plane to meet, don't you?

Dr. RITCHEY. Mine leaves about the middle of the afternoon. I am not in any particular hurry.

Mr. FULTON. Mr. Chairman, with your permission, could I ask for an amplification in the record. I believe you had spoken of your development of the solid fuels and were considering the Hercules, the Minuteman, and the Polaris as well as the X–17 projects.

Would you amplify those a little for us—not here, but in the record, supplying it later? Could you give more specific detail than just referring as I have to the various projects that you have worked upon, the solid-fuel propellants?

Dr. RITCHEY. What type of amplification would you like? Would you like to know the performance figures, the sizes, the weights and what they contain, this type of thing?

Mr. FULTON. The approach and what the differences are.

The CHAIRMAN. Thank you very much, gentlemen. If there is no further business, then, we have one final session on this subject Monday. That should conclude this series of hearings. Isn't that right, Dr. Sheldon?

Dr. SHELDON. That is right, although Dr. Strough is standing by outside in case you want him, either now or tomorrow.

The CHAIRMAN. Ask him now if he would come in and we can release him. We thank you both very much for coming here and your company for sending you down here and permitting you to stand by almost all week. We recognize that as quite a contribution to the committee.

Dr. RITCHEY. Mr. Chairman, it has been a privilege, and I hope you will call on us any time we can provide you any information.

The CHAIRMAN. You will hear from the committee later on. We will call on you.

Mr. FULTON. I would like to enter into the record my compliments to the chairman and the staff for the progress of the hearings. They have been doing very well.

The CHAIRMAN. Thank you, sir.

Dr. Strough, would you come forward and have a seat, sir. We do appreciate your staying over here so that we could ask you a few questions.

I will throw the meeting open to questions. Mr. Fulton, do you have any questions?

Mr. FULTON. No questions at this time.

The CHAIRMAN. Do you have any questions?

Mr. BASS. Not at this time, Mr. Chairman.

The CHAIRMAN. Do you have questions?

Mr. KARTH. No, sir.

The CHAIRMAN. I will ask you a few questions that I have asked everyone practically who has been before us. What is the extent of the Research and Development program of the United Aircraft Corp?

Dr. STROUGH. * * *

The CHAIRMAN. * * *

Dr. STROUGH. * * *

The CHAIRMAN. * * *

Dr. STROUGH. * * *

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Mr. FULTON. Thank you very much. I think it has been very stimulating to hear you.

The CHAIRMAN. If there are no further questions, we thank you very much, Doctor.

The meeting will stand recessed until Monday morning at 10 o'clock.

(Thereupon, at 12:45 p.m., the committee recessed, to reconvene Monday morning, 10 a.m., March 23, 1959.)

SPACE PROPULSION

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
Washington, D.C. Monday, March 23, 1959.

The committee met at 10 a.m., in room B–214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. The committee will come to order.

This morning we have a number of witnesses, gentlemen of the committee. All of the witnesses are here to cover the general problem of propulsion for space.

Now we are going to hear them in open session. When they reach the point where they cannot talk further in open session, we will suspend and then later on go into executive session with all of the witnesses at the same time.

We have Mr. Addison M. Rothrock, Scientist for Propulsion, Office of Program Planning and Evaluation of the National Aeronautics and Space Administration; accompanied by Mr. Elliot Mitchell, Chief of Solid Rocket Development of the NASA; and Mr. A. O. Tischler, Chief of Liquid Fuel Rocket Engines.

We also have Mr. Roy Johnson, Director of the Advanced Research Projects Agency, Department of Defense; accompanied by Mr. William H. Godel, Director of Policy and Planning in ARPA.

I understand that two of the witnesses, Mr. Addison M. Rothrock, and Mr. Roy Johnson, both are going to talk in a general way along the same subject, and therefore it is desirable that we hear them together.

If there is no objection, then, I will ask Mr. Roy Johnson, Director of Advanced Research Projects Agency, Department of Defense, and Mr. Rothrock to come forward and we will hear them at the same time.

Mr. JOHNSON. Mr. Chairman.

The CHAIRMAN. Yes, I was looking for you, Mr. Johnson.

Mr. JOHNSON. My briefing is secret, and therefore should follow Mr. Rothrock's presentation.

The CHAIRMAN. Mr. Rothrock.

Mr. ROTHROCK. I am here, sir.

The CHAIRMAN. Very well, Mr. Rothrock, would you proceed with your presentation?

STATEMENT OF ADDISON M. ROTHROCK, SCIENTIST FOR PROPULSION, OFFICE OF PROGRAM PLANNING AND EVALUATION, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. ROTHROCK. Gentlemen, you have been listening to many discussions on the various types of propulsion systems that we use in the

field of space flight, particularly propulsion systems in forms of chemical rockets, nuclear rockets, and electrical rockets. I thought it might be well to give you a general summary of these various types of propulsion systems and to go into the basic background involved to show the manner in which they are dependent upon well-known laws of physics and chemistry. Further I want to discuss the manner in which we choose our fuels and oxidants and our propellants and also the reasons for using each of the different propulsion systems. I will discuss the more representative types of propulsion systems.

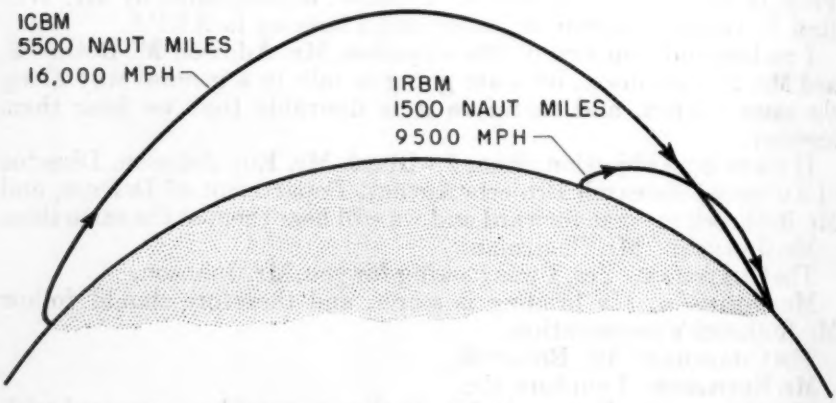
I am not going to advocate any particular type. I will try to give you a reasonable understanding of the different types and why we use them. I am going to talk from slides, and I will use the blackboard somewhat. I am going to give you some two or three mathematical equations. The equations are rather simple. It is not so important that you follow them as it is that you get an appreciation that most of the principles we use can be expressed in a rather simple manner.

Much of the information I give you you will have heard before. I think the grouping of it will be a little preferable to some of the previous discussions that have been given here.

With that I will turn to the first slide (fig. 1).

FIGURE 1

IRBM AND ICBM TRAJECTORIES



Mr. ROTHROCK. It might be preferable if I sit down so that I will not be in the way of any of you gentlemen.

There is listed on this slide the velocity required for an intermediate-range ballistic missile or an intercontinental ballistic missile.

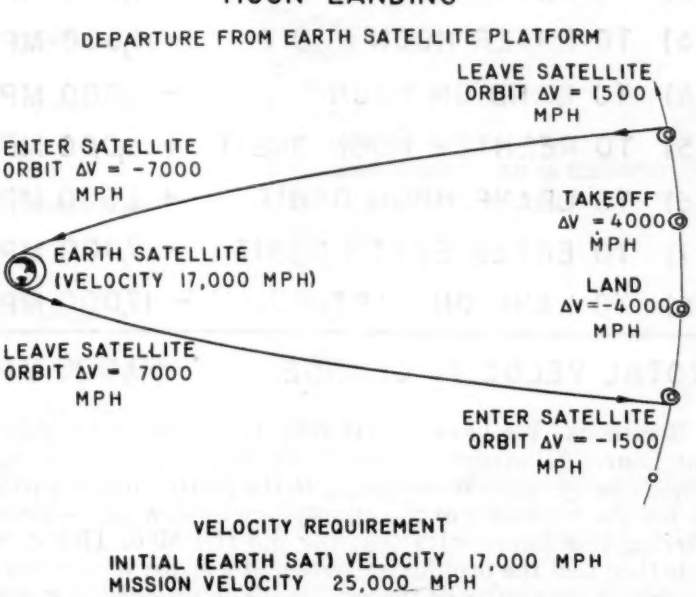
Incidentally, I have put all of the velocities in miles an hour, since it is a term I think you are more familiar with.

The intermediate-range missile requires a velocity of 9,500 miles per hour at the burnout point [indicating]. So we accelerate it to 9,500 miles an hour, and then it goes through its ballistic trajectory.

The ICBM requires a velocity of about 16,000 miles per hour at burnout.

Next we will consider a flight to the moon. That is shown in the next slide (fig. 2).

FIGURE 2


MOON LANDING
DEPARTURE FROM EARTH SATELLITE PLATFORM
LEAVE SATELLITE ORBIT ΔV = 1500 MPH
ENTER SATELLITE ORBIT ΔV = -7000 MPH
TAKEOFF ΔV = 4000 MPH
EARTH SATELLITE (VELOCITY 17,000 MPH)
LAND ΔV = -4000 MPH
LEAVE SATELLITE ORBIT ΔV = 7000 MPH
ENTER SATELLITE ORBIT ΔV = -1500 MPH
VELOCITY REQUIREMENT
INITIAL (EARTH SAT) VELOCITY 17,000 MPH
MISSION VELOCITY 25,000 MPH

The CHAIRMAN. Can all the members of the committee see these slides all right?

I would suggest this: We have members down at the far end. If they would come forward a little, they could see much better. There are vacant seats around the chair.

Mr. ROTHROCK. If we accelerate the vehicle to a velocity of about 17,000 miles an hour, the vehicle will then go into orbit around the earth. Most of you are familiar with that figure.

If we give it another 7,000 miles per hour velocity, it will start into general space. If we aim it correctly, it will approach the moon, and at some point around 200,000 miles from the earth, 40,000 miles from the moon, the moon's gravitational pull will exceed that of the earth, and it will approach the moon. If we then slow it down by 1500 miles an hour, it will go into orbit around the moon and continue there.

If we slow it down another 4,000 miles an hour, it will then land on the moon, and if we increase its velocity from the moon 4,000 miles an hour, we can put it back into a moon orbit; another 1,500 miles an hour starts it on its return journey to the earth.

If it is aimed correctly, it approaches the earth, and if we decrease its velocity by 7,000 miles an hour, it goes into orbit around the earth. If we decrease it another 17,000 miles an hour, it will land on the earth.

These velocities are summarized in the next slide (fig. 3).

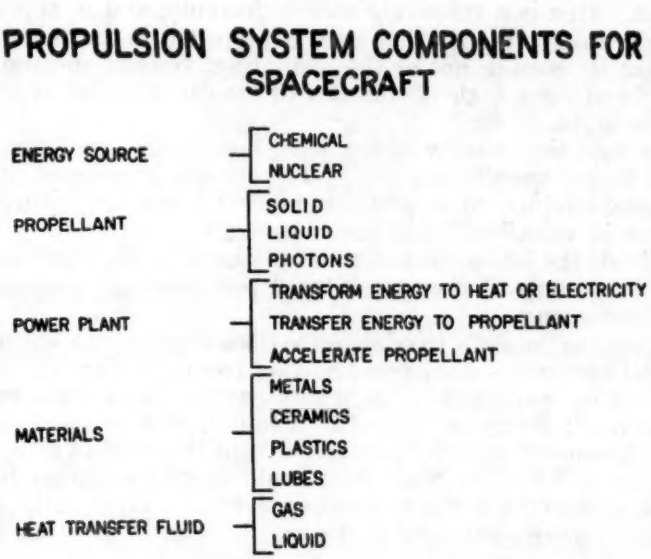
FIGURE 3

(1)	TO REACH EARTH ORBIT	+ 17,000 MPH
(2)	TO LEAVE EARTH ORBIT	+ 7,000 MPH
(3)	TO ENTER MOON ORBIT	- 1,500 MPH
(4)	TO LAND ON MOON	- 4,000 MPH
(5)	TO REENTER MOON ORBIT	+ 4,000 MPH
(6)	TO LEAVE MOON ORBIT	+ 1,500 MPH
(7)	TO ENTER EARTH ORBIT	- 7,000 MPH
(8)	TO LAND ON EARTH	- 17,000 MPH
	TOTAL VELOCITY CHANGE	59,000 MPH

Mr. ROTHROCK. We have a total velocity change of roughly 60,000 miles an hour. All except the last 17,000 will have to be provided by the propulsion system. In returning to the earth from an earth orbit, we can use the resistance of the atmosphere to slow the vehicle down. Considering this figure with that for the ICBM or IRBM, we can conclude then that the propulsion system of a space vehicle is a device for changing the velocity of the vehicle. The propulsion system does not care whether it is asked to increase or decrease the velocity. It is only interested in how much the velocity has to be changed.

On the next slide (fig. 4) we summarize the propulsion system.

FIGURE 4



Mr. ROTHROCK. We have to have some energy source, obviously, to cause changes in the vehicle velocity. The energy can be either chemical or nuclear. We have next what we call the propellant, but before I go to that, I want to use the blackboard.

The propulsion system changes the vehicle velocity by exerting a force, that is a push, on the vehicle. This force is produced by accelerating a mass, the propellant, from the vehicle. This mass, in current systems, is the exhaust jet as discharged from the rocket nozzle. The force, F, is equal to the pounds per second of exhaust gas discharged, $\frac{M_P}{t}$, times the velocity V_J with which the jet is discharged:

$$F=\frac{M_P}{t}V_J$$

Without going through the actual derivation, the change in the vehicle velocity, V_V can be expressed in terms of the jet velocity, the total mass of propellant, M_P, discharged during the velocity change and the gross weight of the vehicle, M_G, at the start of the velocity change:

$$V_V=V_J \ln \frac{M_G}{M_E}$$

in which

$$M_E=M_G-M_P$$

In the equation we use the logarithm (ln). I don't want to confuse you with that term if you are not familiar with logarithms, other than to say if the vehicle weighs five times as much at the start of the flight as at the end of the flight ($M_G/M_E=5$), then this number ($\ln \frac{M_G}{M_E}$) becomes 1.6. If the vehicle weighs 10 times as much at the beginning

of the flight as at the end of the flight, in other words, 90 percent of the vehicle is propellant, the logarithm is 2.3, so we do not get the same effect that we would have if the direct ratio rather than the logarithm was used. This is a relatively simple formula, and it applies to all vehicles in space. We see that we are interested in the velocity of the propellant jet coming out of the propulsion system, and the ratio of the weight of the vehicle at the start of the flight to the weight at the end of the flight.

I have used the velocity of the jet. You people are more familiar with the term "specific impulse." The specific impulse is simply the jet velocity divided by a given number. I can use either specific impulse or jet velocity. I will use both.

If I divide the jet velocity in miles per hour by 22, I get the specific impulse in pounds of thrust produced per pound of propellant discharged per second.

Returning to the slide, in addition to the energy source, we must have the propellant that is discharged as a jet from the vehicle. This propellant can be carried either as a solid, as we do in what we term a "solid rocket"; it can be carried as a liquid, what we term a "liquid rocket"; it could be carried as a gas, except it wouldn't be a very efficient thing to do. The propellant could be photons, that is, energy impulses, energy from the sun reflected from a large sail, or energy from some power system carried aboard. Use of photons is in the future.

Currently, we carry the propellant as a solid or liquid and discharge it as a gas. The propellant is changed into a gas within the vehicle. The gas originally is in the vehicle at zero velocity with relation to the vehicle. We then accelerate it to 6,000 or more miles an hour. This acceleration produces the reaction force which drives the vehicle forward. This is the same whether our energy source is chemical or nuclear.

We have the powerplant proper, the purpose of which is to transform the chemical or nuclear energy into heat or electricity and then to transfer this energy to the propellant and accelerate the propellant and discharge it out the rear of the rocket.

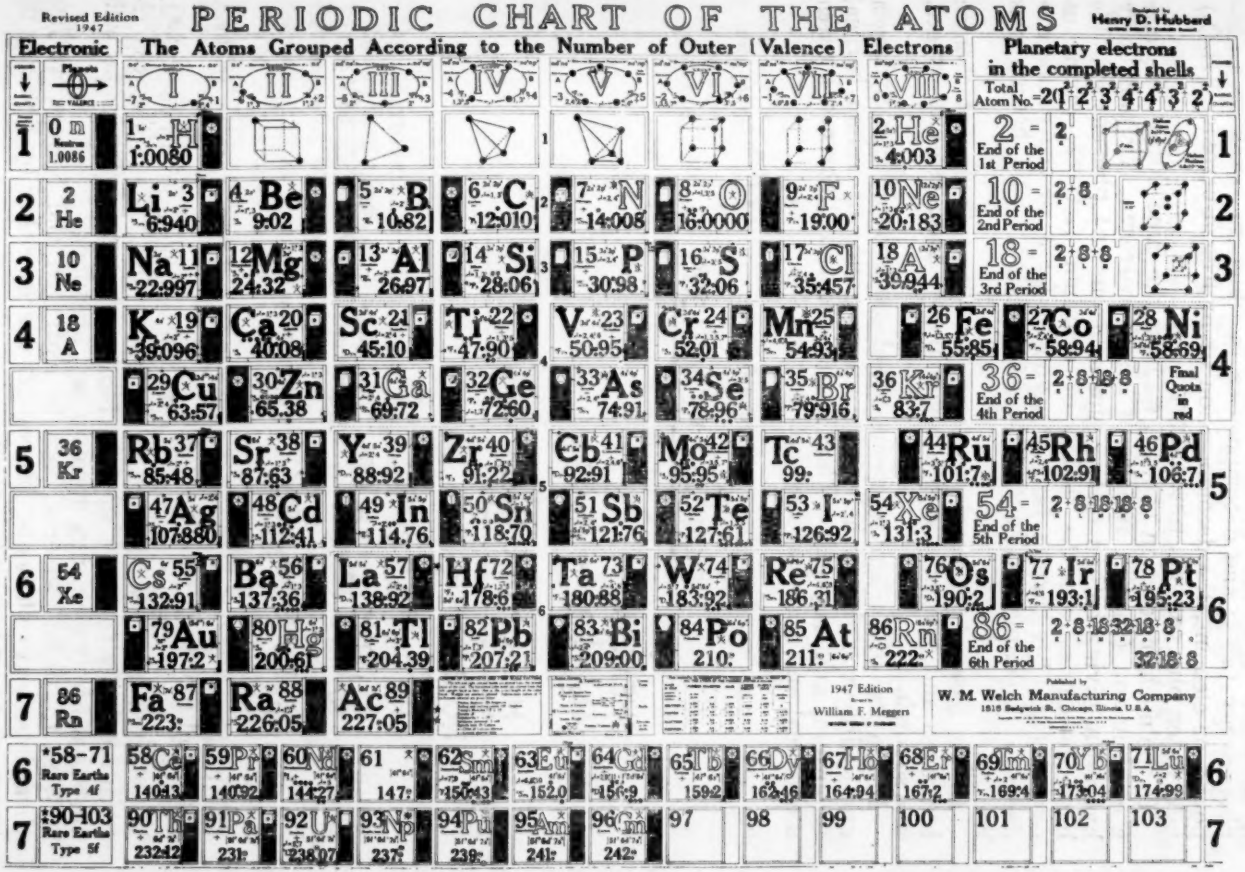
We have the materials of which the powerplant is made—metals, ceramics, plastics, lubricants. I have listed lubricants here for want of a better place to put them.

In certain cases we use heat transfer fluids. We will use them in some of the advanced concepts of space propulsion.

This morning I am going to discuss the energy source, the propellant, the materials, and the powerplant. We will end up by putting them all together and looking at the missions we want to accomplish with them.

I stated that the energy source is either chemical or nuclear. In either case, it must come from one or more of the elements as expressed in the periodic table [indicating], figure 5, and it makes no difference whether I am talking about generating energy in the form of heat or electricity. Any time we are interested in a property of the elements, it is well to plot the property against the atomic number of the element, 1, 2, 3, 4, 5, 6, and so forth, but before we do that, we want to look into the kind of reactions we get in transferring chemical or nuclear energy into heat or electricity.

FIGURE 5


Revised Edition 1947
PERIODIC CHART OF THE ATOMS
Henry D. Hubbard
Electronic
The Atoms Grouped According to the Number of Outer (Valence) Electrons
Planetary electrons in the completed shells
Total Atom No. = 2 + 2 + 3 + 4 + 4 + 3 + 2
I
II
III
IV
V
VI
VII
VIII
0 n Neutron 1.0086
1 H 1.0080
2 He 4.003
2 = End of the 1st Period
2 He
Li 6.940
Be 9.02
B 10.82
C 12.010
N 14.008
O 16.0000
F 19.00
Ne 20.183
10 = End of the 2nd Period
10 Ne
Na 22.997
Mg 24.32
Al 26.97
Si 28.06
P 30.98
S 32.06
Cl 35.457
A 39.944
18 = End of the 3rd Period
18 A
K 39.096
Ca 40.08
Sc 45.10
Ti 47.90
V 50.95
Cr 52.01
Mn 54.93
Fe 55.85
Co 58.94
Ni 58.69
Cu 63.57
Zn 65.38
Ga 69.72
Ge 72.60
As 74.91
Se 78.96
Br 79.916
Kr 83.7
36 = End of the 4th Period
Final Quota in red
Rb 85.48
Sr 87.63
Y 88.92
Zr 91.22
Cb 92.91
Mo 95.95
Tc 99.
Ru 101.7
Rh 102.91
Pd 106.7
Ag 107.880
Cd 112.41
In 114.76
Sn 118.70
Sb 121.76
Te 127.61
I 126.92
Xe 131.3
54 = End of the 5th Period
Cs 132.91
Ba 137.36
La 138.92
Hf 178.6
Ta 180.88
W 183.92
Re 186.31
Os 190.2
Ir 193.1
Pt 195.23
Au 197.2
Hg 200.61
Tl 204.39
Pb 207.21
Bi 209.00
Po 210.
At 211.
Rn 222.
86 = End of the 6th Period
Fa 223.
Ra 226.05
Ac 227.05
1947 Edition
William F. Meggers
Published by
W. M. Welch Manufacturing Company
1515 Sedgwick St., Chicago, Illinois, U.S.A.
*58–71 Rare Earths Type 4f
58 Ce 140.13
59 Pr 140.92
60 Nd 144.27
61 147.
62 Sm 150.43
63 Eu 152.0
64 Gd 156.9
65 Tb 159.2
66 Dy 162.46
67 Ho 164.94
68 Er 167.2
69 Tm 169.4
70 Yb 173.04
71 Lu 174.99
†90–103 Rare Earths Type 5f
90 Th 232.12
91 Pa 231.
92 U 238.07
93 Np 237.
94 Pu 239.
95 Am 241.
96 Cm 242.
97
98
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101
102
103

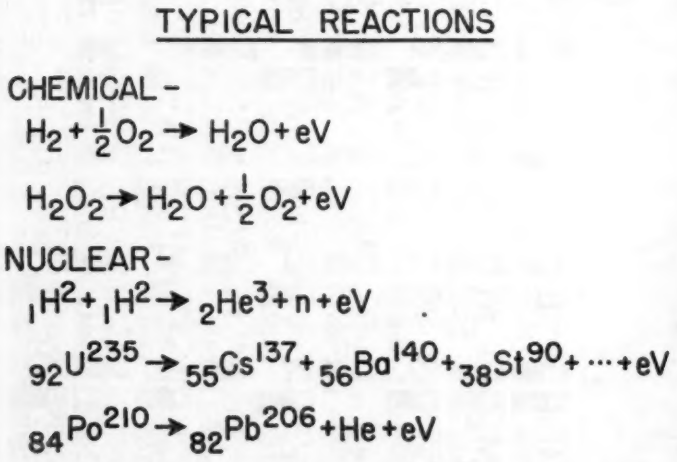
Mr. ROTHROCK. There are in general two types of reactions: combination in which we combine two elements or compounds such as hydrogen (H_2) and oxygen (O_2) (fig. 6), to get water (H_2O) plus energy (eV); and decomposition in which we break up a compound or element, the decomposition of hydrogen-peroxide (H_2O_2) into water plus oxygen, plus energy.

In the nuclear reaction (fig. 6), we have the same thing. We have a combination (that is, fusion) of heavy hydrogen, ${}_1H^2$ plus heavy hydrogen, giving helium (${}_2He^3$) plus neutrons (n) plus energy. We have decomposition, the fission of uranium (${}_{92}U^{235}$), giving us cesium (${}_{55}Cs^{137}$), barium (${}_{56}Ba^{140}$), and so forth, or the radioactive decay of polonium (${}_{84}Po^{210}$) into lead (${}_{82}Pb^{206}$) and helium plus energy.

In the case of chemical reactions, the elements do not change: hydrogen and oxygen giving a compound of hydrogen and oxygen, and so forth.

In the case of nuclear reactions, the elements do change, hydrogen and hydrogen giving us helium; uranium, giving us cesium, barium, strontium, and so forth. That is the essential difference between a chemical and a nuclear reaction.

FIGURE 6


TYPICAL REACTIONS
CHEMICAL -
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O + eV$
$H_2O_2 \rightarrow H_2O + \frac{1}{2}O_2 + eV$
NUCLEAR -
${}_1H^2 + {}_1H^2 \rightarrow {}_2He^3 + n + eV$
${}_{92}U^{235} \rightarrow {}_{55}Cs^{137} + {}_{56}Ba^{140} + {}_{38}St^{90} + \cdots + eV$
${}_{84}Po^{210} \rightarrow {}_{82}Pb^{206} + He + eV$

Mr. ROTHROCK. Now, let's go through the elements in the periodic table and plot their energy release.

First, in a nuclear reaction (fig. 7). From uranium, to your right, we work with fission. That is decomposition. Uranium, you remember, tends to break up into lighter elements. The same with the other heavy elements, down to say, bromine.

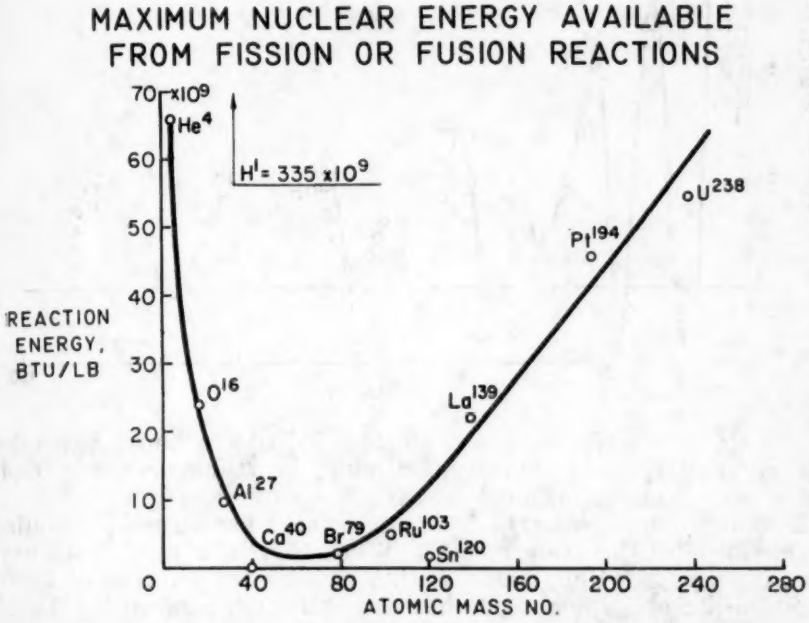
With the light elements, such as hydrogen and helium, we fuse them into heavy elements. So we get energy either by breaking up the atom or by combining atoms.

With the decomposition (fission) of uranium, the energy output is 50 times 10 to the ninth B.t.u.'s (British thermal units) per pound. Don't concern yourself with the actual value. We are interested in the relative value.

If we could fuse hydrogen directly to calcium or bromine, we would get 335 times 10 to the ninth, or roughly 6 times as much energy as with uranium fission. In practice we don't do that. We fuse the hydrogen to helium and again the energy released is about 50 times 10 to the ninth B.t.u.'s per pound.

I have drawn the curve to show the manner in which the points are related. You will notice it is a continuous curve.

FIGURE 7



Mr. ROTHROCK. Now, we go to chemical reactions (fig. 8).

In the first place, instead of having an exponent of 10 to the ninth, I have an exponent of 10 squared. That means the energy here is in the order of $1/10^7$, that is $1/10{,}000{,}000$ of that we got with the nuclear reaction. That is why we want to use nuclear reaction.

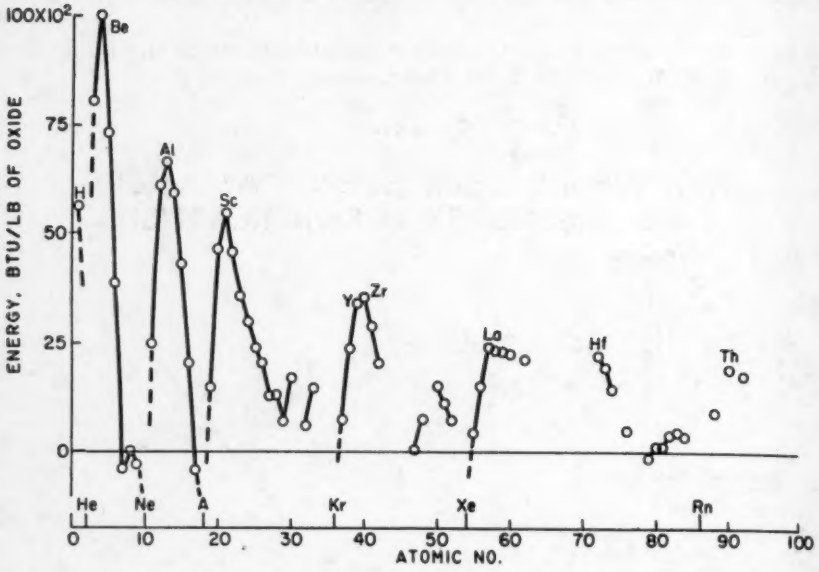
The curve showing the energy released by the chemical reactions is periodic. The reason is that a chemical reaction involves the electrons that surround the nucleus. The number of electrons in the outer shell vary successively from one to eight, and in general the outer electrons are involved in a chemical reaction, so we go successively from one to eight, and go through a series of maxima regardless of the total weight.

The highest energy peaks are with hydrogen (H), beryllium (Be), aluminum (Al) and scandium (Sc). We will look at these areas in more detail.

(Fig. 8 follows.)

FIGURE 8

REACTION ENERGY WITH OXYGEN

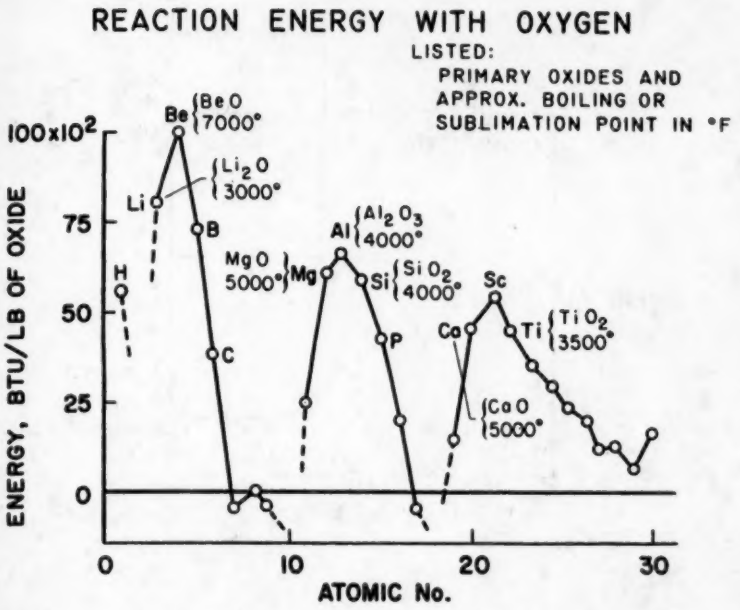


Mr. ROTHROCK. In the next slide (fig. 9), I have simply expanded the curve. We have hydrogen, lithium, beryllium, boron, carbon, magnesium, aluminum, and so forth.

In addition to the symbol for the element, I have listed the boiling temperature of the oxide formed. When beryllium burns with oxygen, it forms beryllium oxide, with a melting temperature of 7,000° Fahrenheit; aluminum oxide has a melting temperature of 4,000°. These are, in fact, what we term "ceramics."

If the exhaust je[t] in our rocket turns from a gas to a liquid at 7,000°, we will get a liquid in the exhaust because we are not working at temperatures above that. Liquids are difficult to use in the exhaust gas and we may not get the energy we want from them. Consequently, these materials that have high boiling points, we will use in small quantities. But whether we are talking about a liquid rocket or a solid rocket, the fuel in general will consist of one or more of hydrogen, lithium, beryllium, boron, carbon, magnesium, aluminum. There is research interest in some of the others.

FIGURE 9

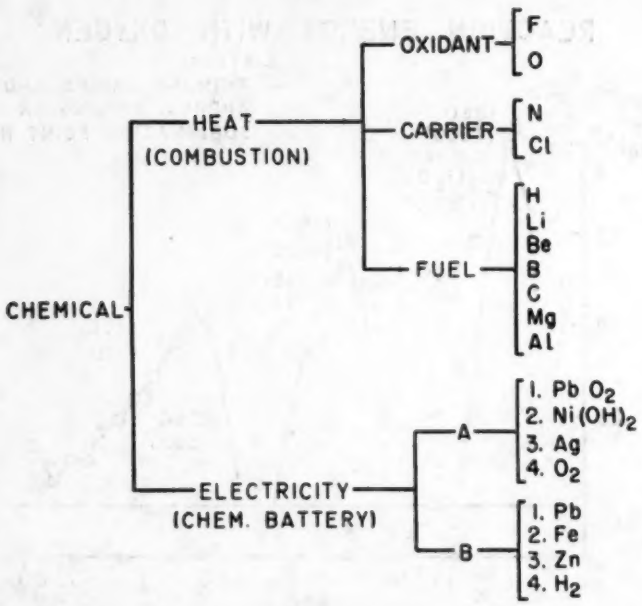


Mr. ROTHROCK. Now, we can tabulate these fuel elements for a chemical reaction in the next chart (fig. 10); to save time I am not going to talk about the section of the slide labeled electricity.

In chemical rocketry we have a fuel which consists of one or more of these elements (indicating). In general, the oxidant will be fluorine or oxygen. From the energy standpoint fluorine is preferable to oxygen. We have listed two elements, nitrogen and chlorine as carriers. They are very handy elements to get these fuels or oxidants into compounds with which we can work.

(Fig. 10 follows.)

FIGURE 10



Mr. ROTHROCK. If we look at a table of fuels and oxidants for rockets, either solid or liquid, we know that we will see these elements, and they will appear and reappear in different combinations. I have shown some of them here (indicating) (fig. 11). I have limited myself to liquid propellants because they are a little simpler to handle from the standpoint of classification.

In the slide we have the propellant velocity in miles per hour, that is the jet velocity, and I have also listed the specific impulse in pounds of thrust, per pound per second of flow, roughly the velocity divided by 22. The specific impulse is the number you are generally given. We start with specific impulses here of 225, using nitric acid ($HNO_3.NO_2$) as the oxidant and kerosene C_8H_{18} as the fuel, and we go up in specific impulse until we have oxygen and hydrogen, fluorine and oxygen, or ozone (O_3) a form of oxygen, and hydrogen.

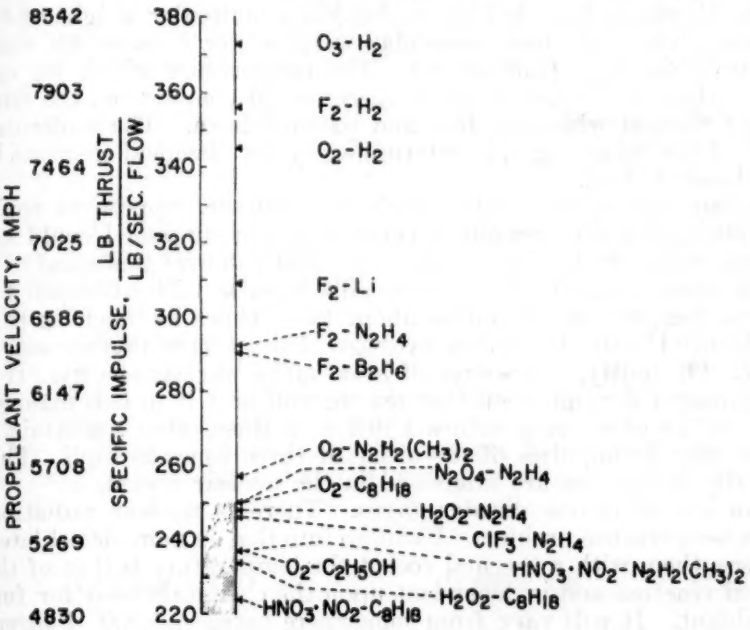
In general, as we go up this scale, we tend to go from solids to liquids to gases. Obviously, it would be simpler if we could use solids, next liquids, with gases the most difficult, because with the gas we have to decrease its temperature to the point that it will be a liquid when we handle it.

Currently, in our large missiles we are using liquid oxygen (a gas at normal temperature) and kerosene. We are definitely interested in the oxygen-hydrogen rocket because of its higher specific impulse. The higher specific impulse, the less propellant you have to carry with you. As I stated before, the thrust produced is the pounds of propellant discharged per second times the jet velocity. Obviously, if the velocity is high, the pounds per second can be low.

FIGURE 11

PERFORMANCE OF REPRESENTATIVE ROCKET PROPELLANTS

P_c = 300 FROZEN EXPANSION P_e = 14.7



The CHAIRMAN. Well, then your most efficient fuel is that ozone fuel?

Mr. ROTHROCK. That is right.

The CHAIRMAN. Why don't you use that?

Mr. ROTHROCK. We do not know as yet how to keep oxygen in the form of ozone. It wants to decompose.

The CHAIRMAN. What is ozone?

Mr. ROTHROCK. Instead of two atoms of oxygen combined to form a molecule, three atoms are combined to form a molecule. It is what we call an unstable compound. Work is going on to try to devise means to maintain it as a stable compound. We know fluorine is better than oxygen, but fluorine is almost a universal solvent. It is difficult to use from that standpoint. Research is going on to solve this corrosion problem.

In some cases hydrogen, a fuel, appears in the oxidant. In some cases you may have oxygen, an oxidant, appearing in the fuel. We don't want that, but in trying to get solids or liquids that we can use, we form compounds of this sort.

The jet velocity, that is, the specific impulse, is proportional to the square root of the temperature (T) of combustion in the rocket divided by the molecular weight (m) of the exhaust gas.

I am going to use the blackboard here just a minute again: V_j varies as $\sqrt{T/m}$

The jet velocity or the specific impulse, either one, is proportional to the square root of the combustion temperature over the molecular weight of the gases in the exhaust gas.

In the first reaction I showed, hydrogen plus oxygen, the exhaust gas is H_2O, which has a molecular weight of 18. If I was using carbon, the exhaust gas is CO_2, which has a molecular weight of 44. Obviously, we want these molecular weights low because we want the ratio T/m high [indicating]. The temperature which we can get in a chemical rocket is the temperature of combustion, the temperature formed when the fuel and oxidant burn. The molecular weight of the exhaust gas, is determined by the chemical elements in the fuel and oxidant.

Now, suppose we weren't limited in this manner, suppose we could use anything for the propellant (exhaust gas); suppose I could use hydrogen with a molecular weight of 2. Well, 18 over 2 is equal to 9, and the square root of 9 is 3, the specific impulse with hydrogen for the same temperature would be about three times as much as that with steam (H_2O). But to use hydrogen I must have another source of heat. Obviously, this source of heat can be nuclear energy. If I pass hydrogen through a nuclear reactor and heat it in this manner, heat it to the same temperature I did with these other materials, I will get specific impulses of the order of three times as high. This essentially is why we are interested in the nuclear rocket.

There are of course disadvantages. There is nuclear radiation, and the temperature problem. I will go into that in more detail later.

We see, then, with a thermal rocket the temperature is that of the chemical reaction and is dependent upon the chemicals used for fuel and oxidant. It will vary from somewhere between 5,000° Fahrenheit to, say, 7,000° Fahrenheit. The molecular weight is going to vary from about 30 or 32 for a current solid rocket to a figure around 22 for a current liquid rocket. If I go to a nuclear rocket, the temperatures may be somewhat lower, but the molecular weight is now going to be down to two.

Suppose we could remove this temperature limitation entirely. Then we would be able to get still higher jet velocities.

In a thermal rocket, whether it be chemical or nuclear, actually what we do when burning or heating takes place is increase the random velocities of the molecules in the combustion or heating chamber. The temperature to which the gas is raised is a measure of the velocity of the molecules, the individual molecules. By expanding the gas through the rocket nozzle random velocities are changed to directed velocities and the exhaust gas is thus accelerated to the jet velocity. This is the basis on which a thermal rocket, either chemical or nuclear, acts.

Is there another means of increasing this velocity rather than through heating?

Yes; there is. If we put an electrical charge on our molecules, and then put the charged molecules in an electrical field, the molecules will be accelerated to a high velocity.

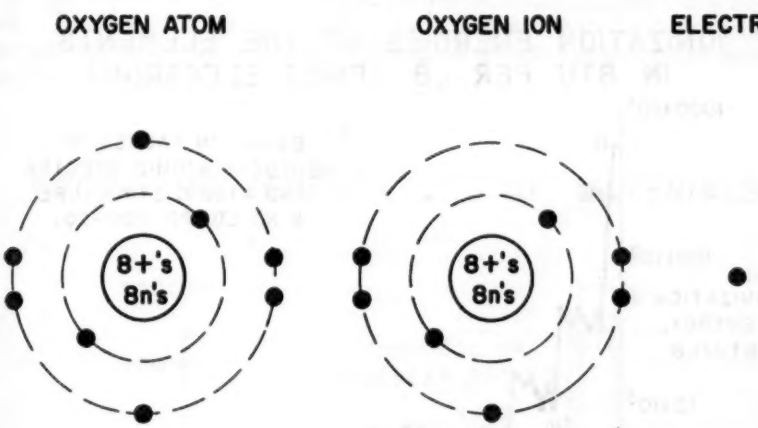
Now we have another equation. The specific impulse or the jet velocity varies as the square root of the charge on the molecule (Q) times the voltage of the electric field (E) again divided by the molecular weight (m). I_J varies as $\sqrt{EQ/m}$

This equation and the previous equation are similar. In each case molecular weight appears. For thermal rockets we have temperatures. For the electric rocket we have charge time voltage. There is a limitation on temperature. This currently is of the order of 5,000° or 6,000° Fahrenheit. There is virtually no limitation on voltage. So whereas I can talk of velocities of the order of 9,000 miles per hour to 25,000 miles an hour for thermal rockets, I can talk of velocities of the order of 300,000 miles an hour for the electric rocket.

Specific impulses are up to 425 with a chemical rocket, with a nuclear rocket, say, up to 1,200. But specific impulses of 10,000 or more are possible with the electric rocket. This is why we are interested in what we call the electrical rocket, the ion-jet or the plasma-jet.

Now, I want to show you what we mean by an ion. The oxygen atom illustrated (Fig. 12), as in the case of all atoms, has a nucleus containing (for oxygen eight) positive charges which we call protons and containing neutral charges, which we call neutrons. Around this nucleus we have the negatively charged electrons in orbit. In this case (oxygen) there are eight. Now, if I remove one of those electrons, I still have eight positive (proton) charges, but there are now only seven negative charges. I have one more proton than I have electrons. Consequently the oxygen atom which we now call an oxygen ion is charged and in an electric field, it will be accelerated.

FIGURE 12



Mr. ROTHROCK. We have used two terms, an ion-jet and a plasma-jet.

In an ion-jet, the electron is physically separated from the ion. It goes through another passage, and is also accelerated electrically.

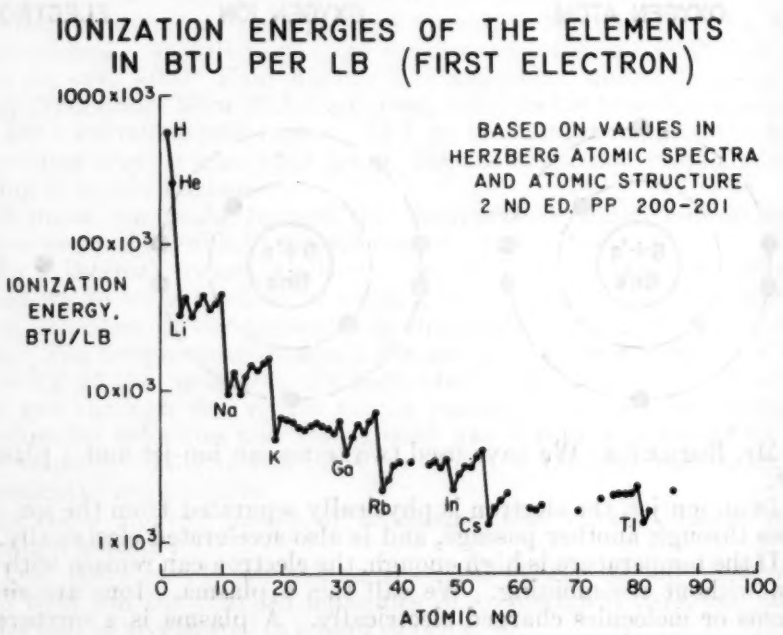
If the temperature is high enough, the electron can remain with the ion without recombining. We call this a plasma. Ions are single atoms or molecules charged electrically. A plasma is a mixture of the ions with the free electrons.

Without going into the details, an electrical field will accelerate an ion gas. An electromagnetic field will accelerate a plasma gas.

Now, it takes energy to ionize a gas that is to knock the electron off. That energy we do not regain. So in either an ion or a plasma-jet we are interested in how much energy it takes to knock the electrons off. Again I go to the periodic table, and for each of the elements I plot the energy in B.t.u.'s, British thermal units, per pound, against the atomic number, and as before we get a periodic variation (Fig. 13). This, of course, is the beauty of the periodic table. We see that the low molecular weight gases we wanted to use with the nuclear reactor, hydrogen, or helium, take a great deal of energy just to knock the electron off. Consequently, we would sooner come down here to the lower energy values [indicating]. Since with the electrical jet we are not concerned with heavy molecular weights, we can use, for instance, cesium, with an atomic number of roughly 55, and with a low amount of energy required to knock the electron off. Also cesium is a liquid at normal temperatures. The elements or compounds we will use for propellants in ion-jets or plasma-jets are not firmed up as yet. We need much more research on them.

Summarizing we see we can use chemical energy but we are limited by temperature and molecular weight. We can use nuclear energy where the molecular weight can be much lower but we still have a current temperature limitation. We can use electrical energy, in which we can use heavy molecules, but since the temperature limitation has been removed and we can get very high specific impulses.

FIGURE 13



Mr. ROTHROCK. Now, why don't we do this?

Well, for several reasons:

There is a particular problem that now comes in, and I will put on what will be my last mathematical formula.

As I said, the thrust produced from a thermal jet or an electric jet is equal to the pounds of propellant discharged per second times the velocity increase of the propellant, the velocity of the jet. Obviously, if I increase jet velocity, I can decrease the pounds per second of propellant discharged. Higher jet velocities therefore mean less propellant to carry and therefore greater payloads.

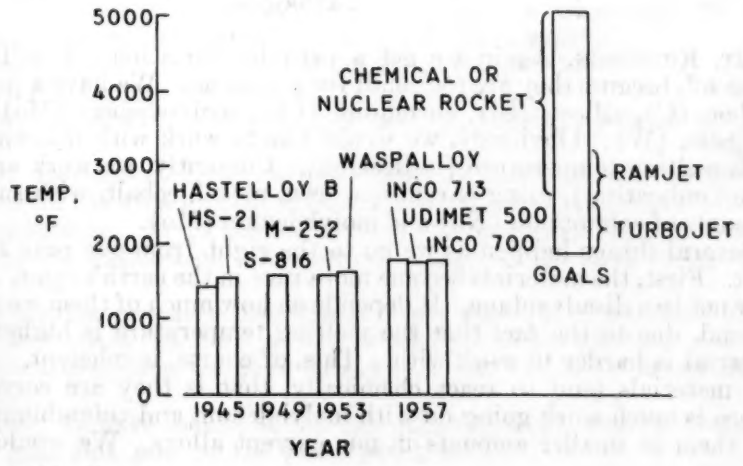
To get these jet velocities I have to put power into this jet, horsepower, kilowatts, whatever we want to call it, and the power (P), required is equal, leaving out a constant, to the propellant rate of discharge (M_P/t) but now times the jet velocity (V_J) squared: P varies as $\frac{M_P}{t}$ times V_J^2. Consequently, for a given thrust, the power required varies directly as the jet velocity.

In our chemical thermal rockets we run about 10 horsepower per pound of thrust. In our nuclear rockets about 30 horsepower per pound of thrust. The electric rockets require about 400 horsepower per pound of thrust. This means that much electrical power has to be generated. This means an electrical power plant of some sort, and current electric power plants are heavy. We will go into this later in more detail.

We have now looked at the propellants, the energy sources, and the means of accelerating the rocket jet. Let's look briefly at the materials we use. In the next slide (Fig. 14) I have plotted the operating temperatures of various alloys (you needn't concern yourself too much with these specific names) against the permissible temperature and the year. These are the permissible temperatures for turbo-blades in turbine-jet engines. This is about the most severe temperature requirement we have currently.

FIGURE 14

OPERATING TEMPERATURE OF MATERIALS

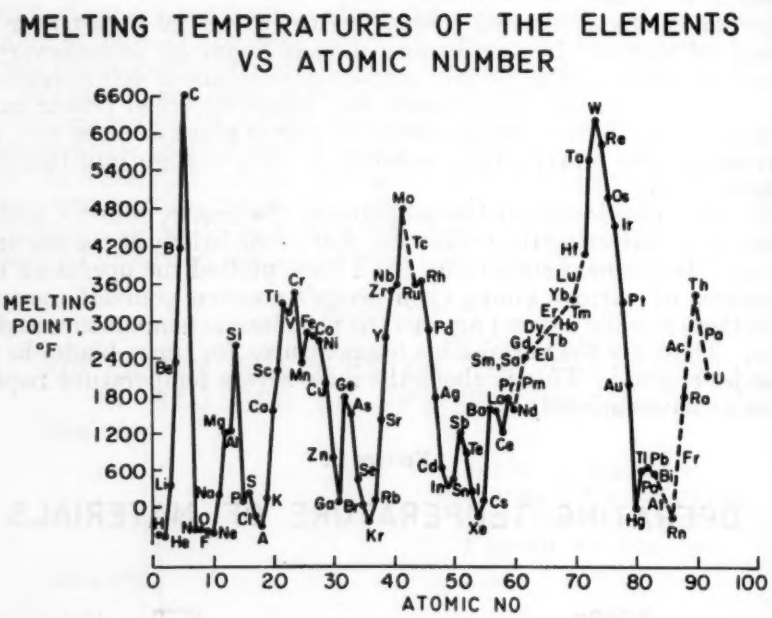


41260—59——18

Mr. ROTHROCK. From 1945 to 1957, a period of 12 years, we have increased that temperature about 300°. There are many highly competent people in well-equipped laboratories working on these material problems. We are, and we should continue to work on them. However, we cannot expect rapid progress. We will hope for it. We cannot tell the operating people we are going to achieve these higher temperatures quickly.

Now, let's look at the situation from the standpoint of the elements, and again we go to the periodic table and this time we plot the melting temperature against the atomic number (fig. 15). You notice that we continually come back to the periodic table and the atomic number of the elements.

FIGURE 15



Mr. ROTHROCK. Again we get a periodic variation. I will read these off, because they are too small for you to see. We have a peak at carbon (C), silicon (Si), chromium (Cr), molybdenum (Mo), and tungsten (W). Obviously, we would like to work with materials of high melting temperature [indicating]. Currently, we work around here [indicating], using chromium, iron, nickel, cobalt, with smaller amounts of columbium (Nb) and molybdenum (Mo).

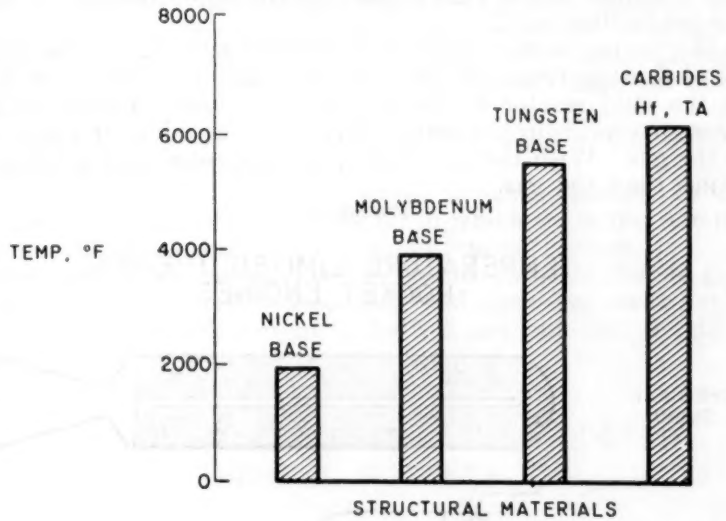
Several things happen as we go to the right from one peak to the next. First, the materials become more rare in the earth's crust. This may not be a disadvantage. It depends on how much of them we want. Second, due to the fact that the melting temperature is higher, the material is harder to work with. This, of course, is inherent. Also, the materials tend to react chemically, that is they are corrosive. There is much work going on with molybdenum and columbium—we use them in smaller amounts in our current alloys. We would like

to use tantalum (Ta) and tungsten, but we must learn how to fabricate them better and overcome their tendency to corrode in the presence of gases. Much research is going on in these fields.

Now, suppose we could go to 80 percent of the melting temperatures of these materials, as shown in the next slide (fig. 16) for nickel base, molybdenum base, tungsten base, and the carbides (ceramics). Currently, we run at about two-thirds of the melting temperature of the major constituent in the alloy. Our goals are now approached.

FIGURE 16

ESTIMATED OPERATING TEMPERATURES FOR MATERIALS



Mr. ROTHROCK. Again in the field of materials we are working hard. We should continue to work hard. Progress is not going to be easy, unless someone comes up with a true breakthrough.

The CHAIRMAN. What is the maximum temperature?

Mr. ROTHROCK. Here?

The CHAIRMAN. Yes, that you can use, usable maximum temperature?

Mr. ROTHROCK. 7,000° with a chemical rocket, would certainly be sufficient. With a nuclear rocket we would like to go to much higher temperatures. In a chemical rocket, the maximum temperature you get is the combustion temperature. There is no need to try to go over that.

With the nuclear rocket the nuclear reactor can go to as high a temperature as the material will stand. We would like to go to higher temperatures than we have here, but we do not as yet know how to do it.

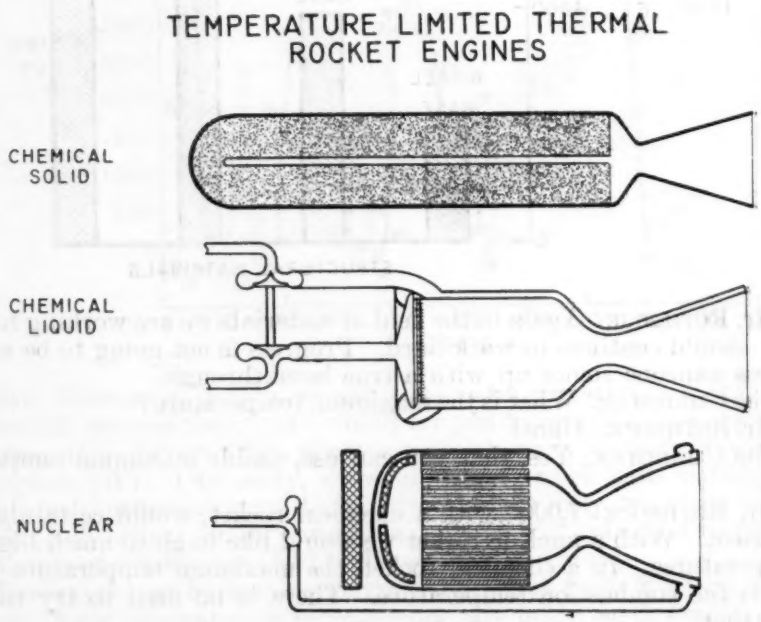
Now, we have looked at the energy, propellant, and the materials. We will look now at the powerplant, itself.

I have here (fig. 17) the thermal rockets, the chemical solid, the chemical liquid, and the nuclear. In the solid, the burning takes place from the inside out. The case doesn't have to withstand too much temperature. The nozzle has to withstand the full combustion temperature for the full duration of burning.

In the liquid rocket I have a tank of oxidant and a tank of fuel. They are forced under pressure or pumped by means of turbines into the combustion chamber. I can take either one of them, generally the fuel, and before I discharge it in the combustion chamber, pass it over the walls of the chamber and nozzle, and thus use it as a coolant. So although the combustion chamber and the nozzle are subjected to the total temperature for the whole duration, I can cool the nozzle and combustion chamber. Consequently, although the solid rocket is limited in the time it can run, the liquid rocket, within reason, is not [indicating].

In the nuclear rocket we have a different situation. The heat, instead of flowing from the gas (the propellant) to the metal, is now from the solid reactor to the gaseous propellant. Consequently, in this case the solids in the reactor have to be at a higher temperature than the gas. With the chemical rocket the solid is at a lower temperature than the gas.

FIGURE 17



Mr. ROTHROCK. We have summarized the situation in the next slide (fig. 18), in which I have listed as chemical propellants, the solid chemicals, RP–1 (that is kerosene) and oxygen; and hydrogen and fluorine. We also have the nuclear rocket with hydrogen as the propellant. Here are the temperatures of the propellants, 5,500 to 7,000 for the chemical rockets. These temperatures can be increased or decreased 500° or so without changing the argument.

The material temperatures are next. For the solid rocket, the propellant case is at a relatively low temperature. The nozzle temperature is shown as 3,500° F. With the liquid chemical rockets, the cooled combustion chamber and the cooled nozzle are at 1,200 to 1,400° F.

With the nuclear rocket the reactor material has to go to a higher temperature than does the propellant. I have listed two temperatures, 3,500° Fahrenheit and 5,500°, without saying anything as to how we can or whether or not we can get these temperatures. In this case the solid has to be at a higher temperature than the propellant. These propellant temperatures [indicating] are therefore lower than the material temperatures [indicating].

When we come to molecular weight—remember, we are interested in the temperature over the molecular weight—in general the solid chemicals have a higher molecular weight than the liquids. We take the square root of the temperature over the molecular weight, multiplied by suitable constants, and get the jet velocity in miles per hour as shown in the last column.

If I divided these velocities by 22, say 20, roughly, I have specific impulse: 250 here, 300 here, 425 here.

We see the manner in which specific impulses increase as we go down the chart. This is the direction in which we would like to go. Temperature is the major problem in our nuclear rockets.

I mentioned if we can increase the specific impulse, that is, the jet velocity, we can carry less propellant and therefore more payload. If I cut the propellent weight in half, I can put that weight into payload.

FIGURE 18

COMPARISON OF TEMPERATURE LIMITED THERMAL ROCKETS

PROPELLANT	TEMPERATURES, °F		EFFECTIVE MOL. WT.	JET VELOCITY MPH
	PROPELLANT	MATERIAL		
		CHEMICAL		
SOLID	5500	600 [1] 3500 [2]	30	5000
RP-1 - O_2	5500	1200	22	6000
H_2 - F_2	5000 7000	1400	11	8500
		NUCLEAR		
H_2	3250 5250	3500 5500	2	14,500 18,500

[1] CASE
[2] NOZZLE

Mr. ROTHROCK. There is another means of getting around this limitation on specific impulse. That is to stage rockets, simply piling one rocket on top of another, firing them successively. In this slide (Fig. 19) I have considered three-stage rockets. I have assumed that the fuel in this first one is kerosene (RP–1), with oxygen as the oxidant, such as we are using at Canaveral in the large missiles. We will assume a payload of one hundred pounds to be used in a moon probe mission, that is, have it go close to the moon. This means roughly that we must give it a velocity from the earth's surface of 24,000 miles an hour.

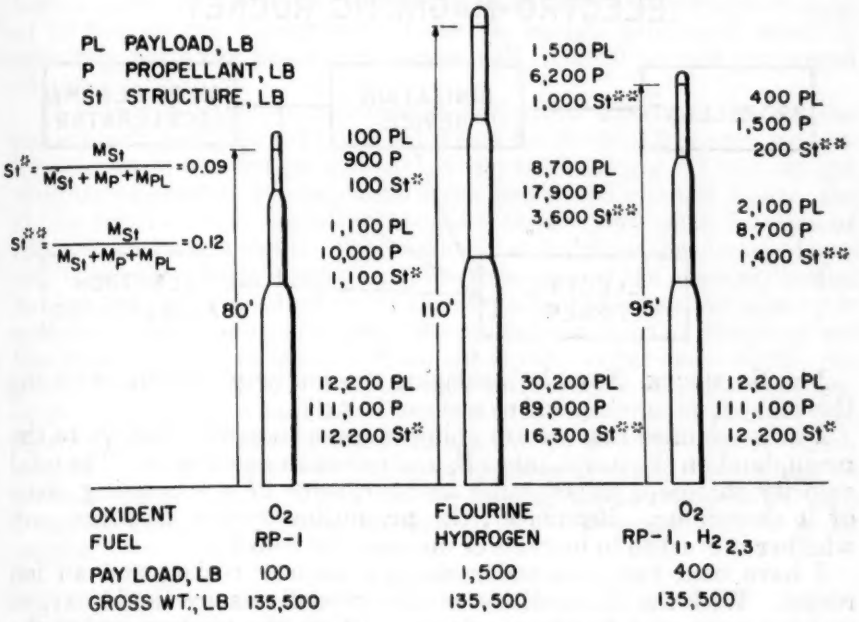
I have arbitrarily decided that the weight of the structure of each stage of this rocket is 9 percent of the gross weight of the stage. Obviously, we want that as low as possible because we want the weight to be propellant and payload. The payload is also assumed to be 9 percent. Therefore, the propellant is 82 percent. I have started with the 100-pound payload and worked back, and I come up with a final gross weight of 135,000 pounds to put the 100-pound payload into a moon probe. This is the kind of numbers we are working with currently.

Now suppose I used a higher specific impulse propellant such as fluorine-hydrogen and suppose I used it throughout the system and started with the same gross weight of 135,000 pounds. Because the specific impulse is now increased, I do not have to use as much propellant and I can put all of the increase in payload. Because these rockets are staged, these increases multiply; I now come up with 1,500 pounds of payload as against the previous 100 pounds.

Why do we not do this now? Because we do not know how. We are doing research on it. Let us go to something we can work with more easily, such as oxygen and hydrogen—and we are working on this now—and let us make the problem a bit easier also. Let us use the same first stage here that we used here; in other words, oxygen and RP–1. Now our gains in the upper stages increase the payload from 100 pounds to 400 pounds. This obviously is worth doing. This is an engineering job rather than a research job such as is the case with the fluorine. I have given a ratio here between weights of stages of about 10 to 1. Normally we use them at about 4 to 1, but the final results are not too different. Until we can get the higher specific impulses we want, we will use staged rockets, and we will use quite a few stages, four, five, six, and even seven stages, when we talk about going to the moon, for instance, landing, and returning.

FIGURE 19

ROCKET SYSTEMS FOR MOON PROBE



Mr. ROTHROCK. So much for the thermal rockets where the energy is either chemical or nuclear. Now we will go to the ion or plasma rocket, the electro or electromagnetic rocket.

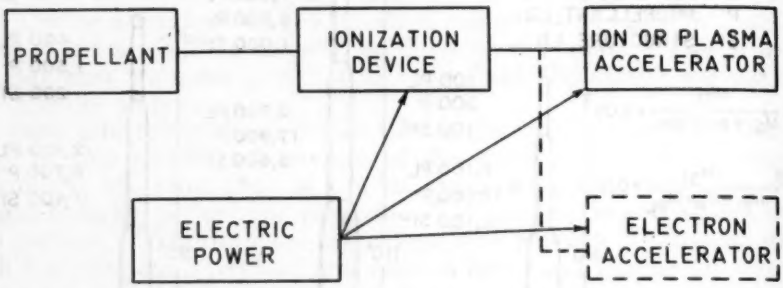
I have shown this rocket (fig. 20) as a block diagram rather than drawing a picture of it. I have done that purposely. We do not know as yet in a definite manner how these propulsion systems will look, what they will look like. Much research must be done on that.

Again we have the propellant, say it is cesium and we have a device, an electrical device in which it is ionized, in which the electrons are knocked off. The energy to do this is electrical energy. That energy is lost. Then we take the electron, if we are going to use an ion, through a separate accelerator from the ion accelerator. By means of an electric field ions and electrons are accelerated to the rear to give our propulsion force. After discharge electrons and ions are again combined. If it is a plasma we do not have to separate the electrons from the ions and an electromagnetic field is used as the accelerative force. Do not be misled into thinking a plasma will therefore be simpler than an ion jet. Based on our current knowledge, the ion jet is more straightforward propulsion. We are doing research on both. When I say "we" I am speaking in broad terms of the Nation as a whole. There is, of course, much research on all of these devices going on in the laboratories and under the contracts of the National Aeronautics and Space Administration.

(Fig. 20 follows.)

FIGURE 20

COMPONENTS OF ION OR PLASMA ELECTRO-MAGNETIC ROCKET



Mr. ROTHROCK. Now, let's compare the ion or plasma jet with the thermal jet, either chemical or nuclear (fig. 21).

I have assumed that we are going to leave an earth orbit, go to the moon, land on the moon, take off, and return to earth orbit. The total velocity change is 25,000 miles an hour, some of it increasing, some of it decreasing. Remember, the propulsion system does not care whether it is asked to increase or decrease the velocity.

I have used two chemical rockets, a nuclear rocket, and an ion rocket. With the chemical rockets the propellants are liquid oxygen and kerosene, and fluorine hydrogen. With the nuclear rocket the propellant is hydrogen. I have again given the propellant velocities in miles per hour. These values are somewhat higher than I gave before because of the different conditions under which we are operating. If I divide these velocities by 22, I have the specific impulses. With the ion rocket using cesium, I have a jet velocity of 300,000 miles an hour, specific impulse 13,600 pounds of thrust per pound of propellant per second.

These large magnitudes should not concern us too much. We simply aren't used to working with them. We will be. We weren't used to working with 600-mile-per hour airplanes 20 years ago. That doesn't concern us too much now.

Again, using the original equation that the velocity of the vehicle is the velocity of the propellant times the logarithm or simply a function of the gross weight of the vehicle at the start of flight to the gross weight minus the propellant used, during the flight we compute this ratio for the different propulsion systems used on this moon mission.

The results are expressed as ratio of propellant weight to gross weight (M_P/M_G) for the first chemical rocket the value is 98 percent; for the chemical hydrogen-fluorine rocket, 93 percent; with the nuclear, 60 percent; with the ion rocket, 9 percent, or say 10 percent.

With the oxygen-kerosene chemical rocket I have to get the payload and the structure in 2 percent of the gross weight. This we do not currently know how to do; 12½ to 7 percent is a more reasonable figure. Consequently, we would have to use rocket staging to overcome the difficulty.

With the nuclear thermal rocket, I am in a pretty good situation. With the ion rocket, I am better off. I could have about 90 percent

of the gross weight for the powerplant, itself, plus the additional structure plus the payload. Now, the difficulty is here [indicating]. It is the horsepower that has to go into the jet. That horsepower is 400 per pound of thrust. If I assume a powerplant, and I am going to have to have this power in the form of electricity, a powerplant weight of 10 pounds per horsepower of electric energy produced, which is currently not a bad figure, the weight will be 4,000 pounds per pound of thrust.

If I have a 10,000-pound vehicle and allow 4,000 pounds for the powerplant, I only have 1 pound of thrust for the 10,000 pounds weight. The thrust is one ten-thousandth of the total weight. Until we get weights of electric powerplants much below the current figure, the thrust for the ion or plasma jets is going to be a very small fraction of the gross vehicle weight. This means I can only use the electrical system when my vehicle is sufficiently far from any of the heavenly bodies so that their gravitational fields are very small or when the velocity is such that it is counterbalancing the gravitational field. I could not use the electric rocket to take off from the earth. After the vehicle is in orbit around the earth, I could use the electric rocket to accelerate it out of the orbit, but it would take the order of—I have forgotten the exact figure—about 40 days. I wouldn't use this to go to the moon, which only takes 2 or 3 days with other propulsion systems. But when we go to Mars or Venus, where we are talking about many days, then I can consider this system because of the low propellant to gross weight.

FIGURE 21

COMPARISON OF ROCKET PROPELLANT REQUIREMENTS FOR MOON LANDING AND RETURN

*ΔV_V = 25,000 MPH

ROCKET	PROPELLANT	$V_{PROP.}$, MPH	$\frac{M_P}{M_G}$	$\frac{HP}{F,\ LB}$
		THERMAL ROCKETS		
CHEMICAL	$RP\text{-}1\text{-}O_2$	6,500	.98	8.6
CHEMICAL	$H_2\text{-}F_2$	9,000	.93	12.3
NUCLEAR	H_2	26,000	.60	35.0
		ELECTRO-MAGNETIC ROCKETS		
ION	Cs^+	300,000	.09	409.0

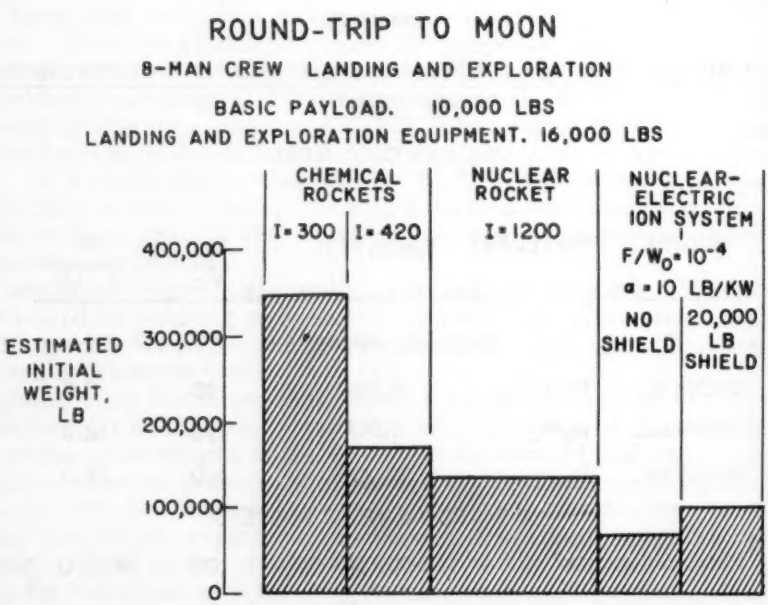
$$V_V = V_{PROP.} \ln \frac{M_G}{M_G - M_P}$$

*ΔV REQUIRED FROM EARTH SATELLITE TO MOON LANDING AND RETURN TO EARTH SATELLITE

Mr. ROTHROCK. Timewise, first we are going to have chemical systems, and I think we are going to use chemical systems. For the more difficult missions we have the nuclear or the ion jet. The picture is not entirely clear between them. The chemical rockets are largely development projects. There is some research. The nuclear and ion rockets are definitely in the research stage as of now.

Let us look at a couple of missions. The first is a round trip to the moon (Fig. 22). It is going to take an eight-man crew. We will land them on the moon from an earth orbit and bring them back to an earth orbit. If I use chemical fuels with a specific impulse of 300, that is a jet velocity around 6,500 miles per hour, and I want to bring back to earth orbit a total load of 10,000 pounds with the men's container, the weight in earth orbit, not from the ground, but the weight in orbit at the start of the trip, would have to be 350,000 pounds. If I used, say, hydrogen-oxygen or hydrogen-fluorine with its higher specific impulse, higher jet velocity, I could cut that down to 175,000 pounds. With the nuclear rocket, and admittedly the statements here are not as accurate, I cut it down to 150,000 pounds. The nuclear-electric system is still lower, but the time to accelerate from the earth's orbit is pretty long. Currently, the choice between chemical and nuclear, is decided in favor of the one we know most about. Currently it is the chemical. We will therefore probably use that first for the moon trip.

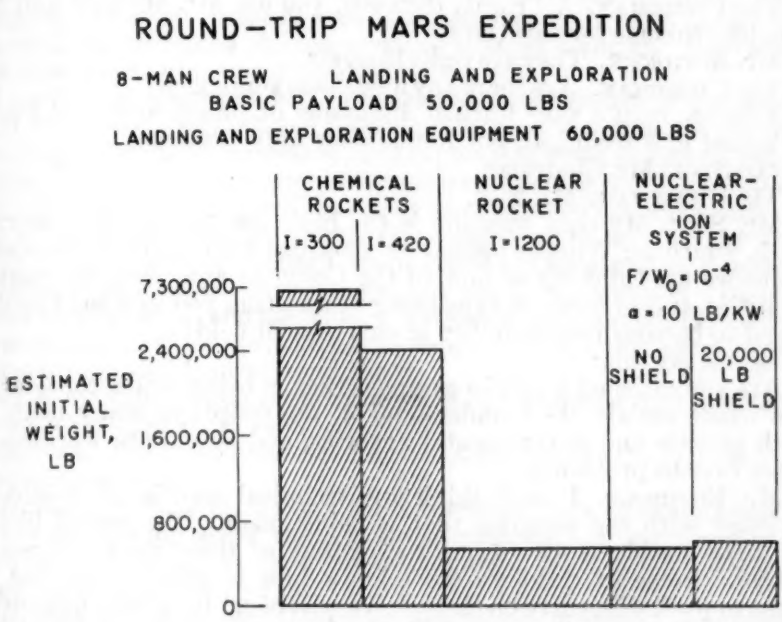
FIGURE 22



Mr. ROTHROCK. Now let's go to Mars (Fig. 23). The situation is different. The required vehicle velocity change is greater, and we will also have a much greater load because we are going to be longer on this trip, the order of a couple of years.

Now, the gross weight, the estimated weight from the earth orbit with oxygen-kerosene is 7,300,000 pounds. That is a very heavy weight, obviously. If I go to the hydrogen-fluorine rocket, I cut that down to almost a third. If we go to the nuclear or ion rocket, I bring the weight down here to say 600,000 pounds.

FIGURE 23



Mr. ROTHROCK. Obviously, for this situation we would much sooner use the nuclear rocket or the electric rocket. The ion or plasma-jets show about the same weights. These are estimates again, based on things we have not done as yet, and there is a certain amount of guesswork that goes into it. But in general we will use, say, first the chemical and then the nuclear or ion or plasma propulsion systems. We will probably use them both.

Gentlemen, what I have tried to do is to give you a brief summary of what we are doing in rocketry, why we are using chemicals, why we want to use nuclear rockets, and why we want to use the electric rockets.

I have also tried to show you that this research and development is an orderly business in which we can put the overall plan together into a single picture. As we get into the unknowns, we are continually looking for new ideas. We hope to get them in the field of advanced rocketry either chemical or nuclear, thermal or electric.

Mr. Chairman that completes my statement.

The CHAIRMAN. Thank you very much for a very fine statement.

Now, we have next on our list of witnesses Mr. Elliot Mitchell, of the Solid Rocket Development, Office of Space Flight Development of the National Aeronautics and Space Administration.

Mr. ROTHROCK. Mr. Chairman, Mr. Mitchell and Mr. Tischler are here to take part in the questioning period rather than in a specific presentation. This concludes the NASA presentation.

The CHAIRMAN. That brings us to Mr. Johnson, whose presentation is to be in the executive session.

Is Mr. Godel here?

Mr. JOHNSON. They should both be in the executive session.

The CHAIRMAN. All right; then will you ask Mr. Mitchell and Mr. Tischler to come forward, sir?

Mr. ROTHROCK. They are right here, sir.

The CHAIRMAN. Are there any questions, gentlemen?

This has been a very learned discussion of propellants, and I have to admit it is technical, but it was very ably presented.

Mr. SISK. Mr. Chairman.

The CHAIRMAN. Mr. Sisk.

Mr. SISK. My only question is the basic question I am concerned with, which is: What is needed or what can be done from the standpoint we are thinking of now of the Congress and what our responsibilities, and so forth, in expediting or assisting you in what I understand to be your responsibility in this overall field?

Let me say this:

Are you satisfied with the progress that is being made, considering the whole basis? As I understand it, the people in many fields, in both private and governmental agencies, and so on, are working on these various problems.

Mr. ROTHROCK. I don't think any technical man is, or should be, satisfied with the progress that is being made. We would like to see these problems solved quicker. Many of them we know can be solved. Some of them we don't know how to solve as yet but we want to work diligently on them. We will be up here later presenting our overall budget to you. I think the better the members of this committee understand the overall picture—and this admittedly is quite difficult—the better position you gentlemen will be in to evaluate the presentations which are made to you.

Mr. SISK. Well, as a specific question, do I understand from your explanation of these various propellants and their use as against the nuclear field, that so far as our immediate goals—and I am thinking now of moon trips, of actually, for example, soft landings, and return, on the moon, that you would expect that that will be done without nuclear equipment?

Mr. ROTHROCK. I think that will be done chemically, because we can do it chemically. The nuclear part will come into it later.

If our research goes along faster than we expect it to, then we will use a nuclear rocket in the upper stages for some of our missions planned for the next few years. I think we will use nuclear rockets in upper stages before we use them in lower stages, from the standpoint of the radiation hazards and the sizes involved.

Mr. SISK. Then following on from that point, it is my understanding from your explanation that to go beyond that, though, nuclear energy is going to be an absolute necessity, that is, some type of nuclear equipment, nuclear propulsion will be necessary when you start talking about Mars or Venus?

Mr. ROTHROCK. With some of the weights we showed there, to do it chemically becomes, of course, quite difficult, and we are getting to the point where the weights become very important. Up to quite a few million pounds, we can probably stand these weights at launch from the earth, but when we start talking about several million pounds in orbit, this is a much different situation, and we would sooner, certainly, do that nuclearly and decrease these weights.

Again, the main research here is in the materials field, to get the materials to withstand the temperature that we want and the radiations that we have to subject them to.

I don't want to seem unduly discouraging in the matter of materials, but I think it is well that you people know what the situation is. We are doing research on materials. We expect progress; and small gains, particularly when they are accumulative, become very important.

Mr. SISK. You mentioned the use of some of these materials, metals, and so on. One thing, of course, that caused me to perk up my ears a little bit, due to the fact that I am interested in encouraging domestic production of some of these minerals—what is the situation with reference to columbium and tantalum? Do you anticipate that if research develops the feasibility of the use of those minerals, that there might be a shortage, did I understand that?

Mr. ROTHROCK. I don't think there will be a shortage for the kind of use we are talking about here.

Mr. SISK. Well, you mentioned we had a shortage in the earth's crust of certain minerals.

Mr. ROTHROCK. Well, I don't think there will be a shortage because we are not talking about them in great quantity. A few years back there were shortages in terms of jet engines. Now, talking about a lesser need for supply, we don't think there will be shortages.

Mr. SISK. Well, we classified them as strategic minerals. I am from the West where we have the mining industry, and I was interested in that.

Lastly, Mr. Chairman, I have this question:

Would you comment on any time schedule at all? I am not asking you for specifics, but moving ahead in an orderly procedure of developing the newer types that will be necessary in this field, to go longer and greater distances and put up more weight, do you want to comment at all on that?

Mr. ROTHROCK. It is always difficult to estimate how long it is going to take us to do something we have never done before. This, of course, is our great difficulty. Going to the hydrogen-oxygen in the chemical field, this is going to come along reasonably quickly. We are talking about a few years.

Now, in the nuclear, it is in, as I said before, what I consider the research stage. If I have to be pinned down to times, which I very much do not like to, I would say in the 5- to 10-year period for nuclear.

Mr. SISK. That is what I was driving at, Mr. Rothrock. You mentioned a moment ago it should be a matter of a few years. Do you mean——

Mr. ROTHROCK. Two years for the hydrogen-oxygen rocket; something like that, less than 5 years.

Mr. SISK. That was the point. I am not attempting to pin you down. I realize that what you are working on might sometimes be

called guesses or calculated risks as to some of these things, and therefore I am not asking you for specific dates. I realize the impossibility of arriving at them. But are we talking in generalities about, let us say, 2 to 5 years or 15 to 20 years?

Mr. ROTHROCK. I would say 2 to 5 years on the chemical, 5 to 10 on the nuclear.

Now, the calculated risk occurs at the time you make up your mind to go into usable hardware. When we decide we are now ready to build one of these things for use, then is when we take our risk, because we always make that decision before we are sure of it, and we should make that decision before we are sure of it if we want progress to be made at the required rate. We always design things and try to build them a bit better than we know how. Consequently, when we are finished, we do what we call taking the bugs out.

Mr. SISK. Well, you touched on something there. I think those of us here on this committee and in the Congress have been very much concerned with just how you arrived at that time to, let us say, stop experimenting and start constructing something usable. I realize we must depend on you people to make that decision, but the progress or the rate of progress, seemingly to me, is rather strongly dependent upon that decision, because we from time to time have military people I know that come down with reference to the application of these things to military programs and they get a little bit perturbed and say, "Well, when are we going to stop experimenting and start building something?"

Sure, we know that we are always seeking something better, but somewhere the basic research has to stop and something be put into hardware, and that becomes important in the overall progress.

Mr. ROTHROCK. That is correct.

Of course, in any case, we don't want the research to stop. It continues because we want this product to be still better.

Mr. SISK. Certainly I didn't want to leave the impression that we wanted it to stop. We never want it to stop.

Mr. ROTHROCK. Again, this has to be done by the judgment of men who are working in the field. If these men are conservative people, the judgment will be conservative. If these men are—I don't know what word I want to use—progressive, the judgment will be progressive.

Mr. SISK. In other words, progress in this field requires boldness and courage to take a calculated risk.

Mr. ROTHROCK. There is no question about that. Just trying to do this requires boldness. We are asking our people to spend a lot of money on these things, and we can't tell them specifically what they will do for them. The whole thing requires much boldness and a large effort.

Mr. SISK. Thank you, Mr. Chairman.

Mr. ANFUSO. Mr. Chairman.

The CHAIRMAN. Mr. Anfuso.

Mr. ANFUSO. I would like to have this question answered either now or in excutive session:

How do our experiments in this field of the chemical and nuclear rockets compare with those of the Russians?

Mr. ROTHROCK. I can give you a general answer in open session because again the Russian literature is much more classified than ours.

I expect they are working on the same general kind of things that we are. All of the information we have indicates that, and we would fully expect that.

You get a group of people who are intelligent and knowledgeable in the field and on the whole these are the roads which they will go up in attempting to attain their goal.

Now, just where they stand in it, I certainly don't know.

Mr. ANFUSO. Mr. Rothrock, as far as nuclear experiments, we started ahead of the Russians, didn't we?

Mr. ROTHROCK. I can't answer that. I don't know.

Any nation that has the facilities in materials, equipment, manpower, would certainly work on these projects. It is the kind of thing you do from your analysis of the problem.

Mr. ANFUSO. Well, we know that the Russians worked on rockets ever since the Sino-Japanese war. But as far as nuclear experiments, I think we are first in that, aren't we?

Mr. ROTHROCK. In the general use of nuclear energy, yes, in explosives. But in the use of power source, I wouldn't want to say. It became so obvious, as soon as the bomb had gone off, then it was obvious to anybody who didn't know before, that work should start on nuclear energy as a source of power.

Mr. ANFUSO. When I came in you were talking about certain essential alloys, and you mentioned tungsten as being a very essential alloy.

Where does tungsten come from, Africa?

Mr. ROTHROCK. It does come from there and from the Far East.

(Mr. Rothrock later submitted the following information:)

Tungsten deposits are generally small in regard to quantity, but are fairly widespread globally. United States capacity is sufficient for our current and foreseen future requirements, but is currently not competitive pricewise with imports.

Mr. FULTON. India.

Mr. ANFUSO. India?

Mr. FULTON. Yes; and Russia.

Mr. ANFUSO. And in any event, that is one of the essential alloys we should acquire?

Mr. ROTHROCK. Yes; as we go to the higher temperatures, we want tungsten. I have not checked into the availability of the materials in the last 3 or 4 years, since we did it in relation to the turbojets, so I am not really up to date on the current status.

Mr. ANFUSO. Well, we do have a program in Congress. As a matter of fact, we passed a bill which was in connection with Public Law 480, to gather essential alloys from all over the world and barter them, as a matter of fact, with agricultural surpluses. You know of that, don't you?

Mr. ROTHROCK. Yes.

Mr. ANFUSO. Do you think that is a good program?

Mr. ROTHROCK. Yes. All of these programs on looking into the availability of these materials, and what we might use them for, where we might get them from, are good programs.

Mr. ANFUSO. One final question——

Mr. FULTON. Before you leave tungsten, would you yield?

Mr. ANFUSO. Yes.

Mr. FULTON. I might suggest that tungsten is now on sale from Russia, and we might buy it from them and use that as a source, because they are very willing to sell it for dollars.

Mr. SISK. Would the gentlemen yield to me on tungsten, because I am very much interested in tungsten.

I have a lot of tungsten in my own district, and there isn't any sale for it. We have a vast stock of domestic tungsten, and because of these imports we can't sell it, and we have no program, I might say, on tungsten.

Mr. FULTON. That is my point. There is more of it than we need.

Mr. ANFUSO. I will yield to Mr. Miller.

Mr. MILLER. When you exhaust that in his district, I am sure the State of Nevada can supply a little bit of it too.

Mr. ANFUSO. I am glad you gentlemen make this contribution.

Do you think, then, we have enough available tungsten in our country?

Mr. ROTHROCK. I can't say, because I have not checked into the availability problems for the past several years.

Mr. ANFUSO. Well, one final question:

Obviously, these experiments of going to Mars and Venus are going to be very costly to the taxpayers. They are going to cost billions upon billions of dollars.

Mr. ROTHROCK. Yes.

Mr. ANFUSO. Of what advantage is it? How can we explain it to the world or to the American taxpayers at least, that we should go to Mars and Venus?

Mr. ROTHROCK. The only way that I can answer it, and of course the answers to these questions have almost become cliches by now, is that the whole history of civilization has shown that we must progress or we will stagnate. This again has to be a thing a person believes. I believe this is true.

Now, as technical progress proceeds, it becomes more vast and more expensive. Again, I don't think there is any choice. We are now at the point where great technical progress can only be made as a national effort of a large and powerful country.

Now, again, to progress, I think we must do these sorts of things. I can't tell you what we will use the results for.

Mr. ANFUSO. I agree with you, but now, as an expert and as a scientist, Mr. Rothrock, can you foresee some tangible benefits to the taxpayers?

I know that in other fields we have saved money. Do you see any tangible benefits?

Mr. ROCKROCK. In the immediate future, yes, in the field of communications, in the field of weather forecasting, probably later weather control. To some extent in the fields of navigation, yes.

I can see great benefits there, benefits that will pay in the matter of dollars.

Mr. ANFUSO. How about in the field of supplying power to the world?

Mr. ROTHROCK. As a corollary to the research, we do in the field of rocketry, yes, and as a matter of fact, in the field of nuclear energy, we should look at the overall field of nuclear energy, considering this as

the most severe demand we are making. If we solve these problems, we will then have better nuclear powerplants for domestic use.

There are always many corollary advantages that come from these things.

Mr. ANFUSO. Now, just one final question.

Russia, I know—and we heard a great deal of this in attending the meeting of the American Rocket Society in New York—Russia has a way of rewarding its scientists. They provide them with an excellent living, and they make some very tangible financial rewards to their scientists besides awarding them all kinds of honors. We may give them a ticker-tape parade or something like that and that is the end of it.

Do you think that it should be the policy of the Congress to provide some system of rewarding our scientists who make some unique discoveries?

Mr. ROTHROCK. I learned early in my some 30 years in Government that the satisfactory salary is that of the grade above the grade you are in at the present time. I think the most satisfactory system of awards is one in which a man's overall value to the organization is recognized in his salary and that he continually have the opportunity to advance in pay as his services become more valuable.

Again, we don't know who is going to catch the forward pass. We don't know who is going to make what we call the actual "find." It is based on a highly cooperative or highly coordinated effort. I think what is also required is a genuine increase of appreciation by the Nation as a whole of the things scientists and engineers are doing.

Mr. ANFUSO. Well now, you spoke very nobly, and I appreciate that. But what I said a moment ago came from scientists. They believe that they ought to get something more tangible than a ticker-tape parade or something like that.

Mr. ROTHROCK. Well, yes; specific awards are beneficial, I think, particularly with the younger men who are starting in their career. I think we all want recognition, of course, and to have the recognition of one's peers and the older people in the field is a very satisfying thing. There are, of course, quite a few awards given by the various technical socities. However, there always is difficulty in giving the awards in making the judgment as to who should and who should not get them.

Mr. ANFUSO. I also think that a system of supplying security to these younger men, as you spoke of, giving them a future life in a secure position, I think that that is sort of an incentive, isn't it?

Mr. ROTHROCK. Yes. And that depends a great deal on the national policy. Are we going to continue at a given level, or increasing level, rather than having dips and peaks in what we do? That, of course, is quite bad. It hurt us in the early 1950's.

The CHAIRMAN. I don't want to interrupt here, but we do have some other witnesses.

Mr. ANFUSO. That is all, Mr. Chairman.

The CHAIRMAN. Mr. Fulton, you have some questions?

Mr. FULTON. May I be told when 3 minutes have expired, Mr. Ducander?

The CHAIRMAN. Let him know, Mr. Ducander, when 3 minutes are up.

Mr. FULTON. I wish you would; yes.

Mr. Rothrock, we are glad to have you here. I don't know whether you remember, but I knew you as Jim Fulton when you were Rothrock at Penn State. I was a friend of J. W. (Bill) Hines at Dayton, Ohio, in Air Force research.

I am glad to hear you say that the Russians are working on the same general kinds of things we are in the missiles and space programs, because it shows (on the general level of research and development in scientific programs) that we have a broad base program in the fields that we believe reasonably should be covered. I would guess they have the same kind of program going too, and we would be ahead in many departments while they will be ahead in many others, isn't that correct?

Mr. ROTHROCK. Yes; that is correct.

Mr. FULTON. And in the nature of things, if we will keep a current and steady effort on our scientific research and development, instead of these peaks and valleys, with the wide base of our program, we should measure up pretty well in the world progress; is that not right?

Mr. ROTHROCK. Yes.

Mr. FULTON. Now, let us speak a little bit of the cesium.

How much research is being done on that? I think that is one of the very heavy elements, isn't it, about 37 times the molecular weight of hydrogen?

Mr. ROTHROCK. Yes; it is fairly heavy in atomic weight.

Do you mean the ion propulsion, as such?

Mr. FULTON. Yes.

Mr. ROTHROCK. There is much research on the ion or plasma jet in both the NASA laboratories and elsewhere.

Mr. FULTON. My comment is: Is research on the nuclear and the ion-jet propulsion systems adequate in your estimate?

I have made the point previously—maybe we should bring somebody in that will correlate all of that higher type propellant program and maybe get Admiral Rickover to give it a push and cut the redtape and help people like you and Roy Johnson.

Mr. ROTHROCK. Presumably, the Space Council is to present an overall program in the field, and the staff of the NASA will assist in bringing these programs together into a single document so that one can better evaluate what is going on.

Now, again, I don't think any scientist is satisfied with the progress that is being made or satisfied with the expenditures that are being made. I am not directly connected with the budget. I cannot tell you as of now what the expenditures are. I do know that in the field of the ion and plasma jet, the equipment becomes quite expensive, because we have to operate in a very low vacuum and with highly specialized equipment. This is one of the occupational facts of the spacework. We are trying to work where there is no air, and to do that on the ground isn't very easy.

Mr. FULTON. I want to thank you and say to you that our Pennsylvania public school system is very proud of you, and I as a Pennsylvania taxpayer am likewise proud.

Mr. ROTHROCK. Thank you.

The CHAIRMAN. Any further questions?

If not, we thank you gentlemen very much for your fine statements.

Now we have two more witnesses. We have Director Roy Johnson

of the Department of Defense, Advanced Research Projects Agency, and Mr. William Godel, of the Advanced Research Projects Agency, Director of Policy and Planning, and I think both of them want to testify in executive session.

Is there anything that we could give in open session to the press before we go into executive session?

Would you care to give us anything in open session about the radio umbrella in the South Pacific?

Mr. JOHNSON. We don't have any statement for open session with us, Mr. Chairman, this morning.

The CHAIRMAN. There is no statement you could make to the press.

Then we have no alternative. The committee will go into executive session to hear these two witnesses.

(Whereupon, at 11:30 a.m., the committee proceeded in executive session.)

EXECUTIVE SESSION

The committee continued in executive session at 11:35 a.m., in room B–214, New House Office Building, Hon. Overton Brooks, chairman, presiding.

The CHAIRMAN. The committee will please come to order.

Will you check and advise me whether everybody remaining here is cleared?

If not, have them leave.

Mr. FULTON. May we say to Roy Johnson before he starts, if we were in Russia, he would be labeled hero, first or second class, in his presentation here.

The CHAIRMAN. There was quite a delay before we could get to him before, and now there is another delay. It was not through any lack of appreciation of the value of his testimony.

He tells me he will be glad to come to this committee later in executive session and tell us about what happened there in the Argus shots when they sent up those high-altitude rockets with nuclear warheads. We will be happy to have you later on on that.

Today you want to talk to us about propulsion.

STATEMENT OF ROY W. JOHNSON, DIRECTOR, ADVANCED RESEARCH PROJECTS AGENCY, DEPARTMENT OF DEFENSE

Mr. JOHNSON. Mr. Chairman, it is a pleasure to meet with you and your committee again and to discuss with you certain aspects of our national space vehicle propulsion program.

As has already been outlined for you by the representatives of NASA, the United States has embarked upon the development of a family of space vehicles under an integrated national program designed to insure the availability of adequate propulsion in the earliest possible time period for both civilian and military requirements.

This national propulsion program was presented to the President, to the Space Council, at the last meeting, and has been endorsed and approved by the President, and changes in that program of any magnitude go back to the Council and to the President for his approval, if changed.

Let me reiterate that our booster program is a national program. It has been carefully coordinated between the several agencies reporting to ARPA and NASA. It will take maximum advantage of and push ahead the "state of the art," insuring that we so mobilize our industrial resources as to obtain the kind of vehicles required for our program without unnecessary duplication and with maximum economy. ARPA's present role in this booster program, outside of the missiles designed for ballistic missile purposes, is primarily concerned with the development of the Saturn, which is the 1,500,000-pound cluster you are familiar with, and the Centaur, the high energy, upper stage.

I am satisfied that the program, if pursued as presently outlined, will provide us with the kind of space "trucks" we need to do the jobs we have in mind for these vehicles, in the military at least. We are now facing a decision as to the upper stages for the clustered booster. We definitely intend to use the Centaur as the third stage, and then we will have other modified fourth stages. As far as we are concerned, the planning of this big booster, which can put 50,000 pounds into a 300-mile orbit, is well along.

In addition to the actual development programs as outlined for you by NASA—those programs to obtain space trucks we know we can build—we are also actively engaged within the Defense Department in looking ahead of these programs, seeking to exploit the kind of breakthrough research which may lead us to wholly new means of propulsion. In the final analysis, the rocket is not a new invention. The principles of rocket propulsion were well known 5,000 years ago. It is equally true that a rocket—while it may be today the only known means of achieving massive propulsion in space—is inherently an inefficient source of energy.

Although it is always impossible to invent new things on a time schedule, we believe that a considerable measure of our effort must necessarily be devoted to finding new methods for fulfilling anticipated propulsion requirements. For this reason the Department of Defense has two programs supplementary to the national space vehicle program, one for work in the field of advanced propulsion, the other for quantum improvement of solid propellant fuels.

As to the program for advanced propulsion, we have let a million dollar feasibility study contract to examine a new method for achieving massive propulsion in the field of controlled nuclear detonations. We have also undertaken work with advanced space propulsion devices.

* * * * * * *

For our purposes, desired performance can vary over a wide range, starting where high-energy chemical fuels leave off and going to a value of five or so times as great. There is expected to be a series of performance tradeoffs; for example, obtaining both high performance and high thrust from the same system is unlikely. Consequently, study and research on a broad front is essential to provide the variety of propulsion types which will be needed. This is particularly true of the lower specific impulse, higher acceleration category, which appears important for many military applications. Of course, efficiency of the

thrust device is always vital to keep down the weight of the heavy propulsion power supply.

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In completing this review of the ARPA advanced propulsion program, I should like to note that it has been planned to dovetail with other existing programs, with emphasis on foreseen military needs for greater and faster maneuverability.

As I have testified previously, we in the Department of Defense are not interested in military maneuvers to the Moon or Venus or Mars, but we are interested in maneuvering in the upper atmosphere with military spacecraft.

I should next like to discuss the substantial program which we call solid propellant chemistry.

This latter program may be of most interest to you this morning. Solid propellants enjoy an important position in our defense posture. Research has been actively in progress in this country since early in World War II. Improvements in solid propellants formulations and in the technique of their utilization in solid engines have made possible the large solid engine rockets now under development, such as Sergeant, Nike-Zeus, Pershing, Polaris, and Minuteman.

The useful energy of solid propellants is designated by the term "specific impulse." By specific impulse we mean the pounds of thrust developed, multiplied by the duration of the thrust and divided by the weight of propellant consumed. Values of this parameter for propellants now projected for use in * * * are in the range from 240 to 250 seconds. It is the objective of the ARPA solid propellant program to increase this value by at least 10 percent.

* * * * * * *

In setting up our program we have contracted with a large number of industrial, foundational, and academic institutions. In the selection of contractors, emphasis has been placed upon the quality of the scientific talent available to us. We believe that we have an outstanding group of contractors.

These programs have been developed in cooperation with the technical personnel in the Army, Navy, and Air Force, through an open competition. In most cases the contracts are set up and administered by the three services. We believe that this arrangement is advantageous in that it allows very close coordination between the advanced program in solid propellants of ARPA and the propellant programs of a general and supporting character which are the responsibility of the services.

Please note that a very large amount of propellant development is carried on as a part of the missile systems developments which utilize solid propellants. It is the intent of the Advanced Research Projects Agency to carry our projects in the solid propellant field only to the point where they can and will be utilized by those responsible for weapons systems development.

A summary of our current program follows:

Contracts with industry, $10 million.

Contracts with universities and research foundations, $2 million.

Contracts with Government laboratories, $3 million.

Total, $15 million for fiscal year 1959.

In closing, we have been asked to comment briefly on certain testimony provided you by the various contractors and technical personnel who have appeared before you during the past several days.

The substance of the question as we understand it lies in the conviction of the several contractors that they could usefully expand their programs, and, with such expanded programs, produce large rockets more quickly. It is always difficult to respond precisely to this kind of statement.

You will remember that we refer to large rockets as trucks. They are in many respects no more than carriers for experiments or programs and, therefore, have value only in terms of their ability to launch equipment or personnel into outer space on demand. It is, of course, always true that if we possess more trucks, we can place more experiments in space sooner. The problem is one of weighing this capability against need and against the validity of the number of experiments or operations to be conducted in space.

In some respects, one is obliged to answer that, given funds, a family can buy three or four automobiles. The question is whether one or two automobiles satisfy the family's requirements. When resources availability is taken into account—and I think we must always keep the overall resources of the United States in mind—there is also the question of balancing the ability to produce equipment today against the possibility of producing significantly better equipment tomorrow, without prejudice to the achievement of today's requirements.

I believe that the programs as outlined to you today provide an optimum balance in producing state-of-the-art equipment for today's programs and producing new equipment against tomorrow's requirements.

I believe it important that we always keep this necessary balance in mind. We are now prepared to answer any questions you may have.

The CHAIRMAN. Thank you very much, Mr. Johnson.

We appreciate your statement.

I would like to ask you two or three questions.

For instance, you refer to the fact that you are interested only in military projects, and that is natural.

ARPA was created for that purpose, and it is natural that you should wish to confine your projects to those that have an obvious military significance, but as I move along in this program, I have changed my own mind, and I suppose you do, too, as to what really has a military significance.

Originally, I was of the conviction that ballistic missiles had a military significance, but when you got projects of satellites, they did not. Now I am convinced that they do have a military significance.

Is that your view?

Mr. JOHNSON. I think increasingly, Mr. Chairman, we have to take very seriously the potential ability of a possible enemy to use the space environment against us in a military way, and we must be prepared, I think, to take advantage of that same capability, and more and more I see space environment is going to be used in the military fashion.

The CHAIRMAN. And as you proceed, do you raise your sights and look even higher than ballistic missiles and satellites?

Mr. JOHNSON. Yes, sir.

The CHAIRMAN. You feel that an excursion to the moon, however, would not have a military significance at this time?

Mr. JOHNSON. No, sir. * * *

The CHAIRMAN. And the deeper probes would have less military significance, even than the moon probe?

Mr. JOHNSON. Yes; I would like to clear up something I said the last time I appeared here.

From the military viewpoint, we are definitely interested in 24-hour satellites, which means 22,000 miles. These trucks that we are talking about, such as Saturn. * * * The purpose of this is to get up into that orbit, 5,000 pounds, let us say, that would house a complete communications system, with batteries with very long life.

We think this is a straightforward thing and can be accomplished in some years on a program basis. Beyond that, we do see the need to use this environment up to at least 600 miles for maneuvering in space, and we therefore do need the exotic kind of propulsion that you would use in outer space to maneuver these vehicles at will.

Therefore, our sights have been set much higher in regard to the kinds of propulsion that were discussed so well this morning. * * *

The CHAIRMAN. So that if there is developed exotic means of propulsion, you would certainly use them if they were acceptable to your needs there?

Mr. JOHNSON. Yes, sir.

The CHAIRMAN. Regardless of whether they were used in a Moon probe or a Venus probe or whatever it was, so that after all, there is a possibility that these developments will all have military significance. You answered that affirmatively, did you not?

Mr. JOHNSON. Yes, sir.

The CHAIRMAN. Now, you refer to $15 million in contracts.

Now, those are contracts for the purpose of developing your propellants?

Mr. JOHNSON. Solid propellants.

The CHAIRMAN. Do you have a list of those contracts?

I have asked staff for the committee, where it is possible, to show the extent and the diversification of the interest of this program to the country, to get a list and have that available.

Mr. JOHNSON. We would be very happy to give you a complete list of the solid propellant contractors, and there are many, including universities, including some very small research operations.

The CHAIRMAN. Is it classified, the list?

Mr. JOHNSON. The names, I don't believe we would classify the names of the contractors; no, sir.

(The list referred to is as follows:)

List of solid propellant contractors, Mar. 26, 1959

I. INTEGRATED PROGRAMS

	Cost, in thousands
Awarded:	
Minnesota Mining & Manufacturing	$1,467
American Cyanamid	816
Dow Chemical	1,714
Esso Research & Engineering	1,214
Total	5,211

II. SPECIALIZED PROGRAMS

Awarded:	
Aeronutronic Systems	615
Applied Physics Lab	550
Callery Chemical	100
Total	1,265
Being processed for contract:	
Magna Propulsion	66
Atlantic Research Corp	170
Olin Mathieson	392
Allied Chemical	733
Olin Mathieson	517
Monsanto Chemical	51
Pennsalt	104
Borden	58
Peninsular Chemresearch	127
Ethyl Corp	505
Atlantic Research Corp	275
National Research Corp	150
Total	3,148

III. BASIC PROGRAMS

Awarded:	
Ohio State University	80
Princeton University	180
Aerojet-General Corp	86
Aerochemical Research Lab	25
New York University	220
Total	591
Being processed for contract:	
University of California	70
Polytechnic Institute of Brooklyn	40
Penn State University	95
University of Texas	69
Stanford Research Institute	33
Aerojet-General Corp	50
Aerojet-General Corp	94
University of California	200
Materials Research Corp	46
Duke University	33
A. D. Little	259
Vanderbilt University	84
University of Florida	60
University of California	45
Total	1,178

List of solid propellant contractors, Mar. 26, 1959—Continued

IV. IN-HOUSE PROGRAMS	*Cost, in thousands*
Materials Lab, WADC	$83
Army	250
Navy	250
Air Force	250
Rohm & Haas	500
National Bureau of Standards	500
Allegany Ballistic Laboratory	405
Bureau of Mines (Pittsburgh)	65
Bureau of Mines (Bartlesville)	150
NOTS, NOL	200
Total	2,653

The CHAIRMAN. Now, why is it necessary to classify the amount of money that you are putting into the solid propellant field?

Mr. JOHNSON. That is not classified, sir.

The CHAIRMAN. So you would release that?

Mr. JOHNSON. Yes.

The CHAIRMAN. The $15 million?

Mr. JOHNSON. That is not classified.

The CHAIRMAN. What about what you are spending on liquid propellants; do you have that figure?

Mr. JOHNSON. We do not have any work in liquid propellants. This is being done by the services, themselves. We are dealing only with solid propellants, because of the need to have a breakthrough here of a high order.

The CHAIRMAN. And it is very urgent with your solid propellant that you do have a breakthrough, whereas you don't need the breakthrough with the liquid propellant?

Mr. JOHNSON. We have carried that as far as it can go in the regular routine.

Mr. MILLER. Would the gentleman yield for a clarifying question?

The CHAIRMAN. Mr. Miller.

Mr. MILLER. Is ARPA entering into these contracts on the solid propellants, or are the several services individually?

Mr. JOHNSON. The several services. We have used the service field agencies to execute the contracts for us in every case.

Mr. MILLER. But then ARPA isn't doing it?

Mr. JOHNSON. ARPA is not. We have the authority to do it.

Mr. MILLER. You have the authority. But you are guiding the overall so there is no duplication?

Mr. JOHNSON. That is our principal function; yes.

The CHAIRMAN. Another question: How about Argus; is that a military program?

Mr. JOHNSON. * * *.

The CHAIRMAN. * * *.

Mr. JOHNSON. * * *.

The CHAIRMAN. * * *.

Mr. FULTON. We are glad to have you here, and we think you are doing a fine job in the program, both of you.

Secondly, I think that it is wise to have people in various fields push the research and development, especially in the fields of their own special interests, because it gets more than just a basic research position on it.

There is some reason for doing it, so that rather than feel that the space program is in too many areas in the Government, I like the feeling that it is being developed on various lines, military and civilian, in various agencies.

I do think that the time has come when the Space Council and the President should make the decisions overall and correlate them for the whole space program for the country, and I am very pleased to hear that there is such a decision already made by the Space Council and at the Presidential level on the national space program.

Is that public, is that decision of the last meeting of the Space Council, the national space program, for boosters, approved by the President, which has been reviewed and ready for implementation?

Mr. JOHNSON. * * *

Mr. FULTON. I am writing a magazine article for Missiles and Rockets, and I certainly would like to have that by sometime this afternoon, because I am under attack by Senator Symington on justifying some of these plans, and we are each writing a lead article, he on the right and mine on the left, down one of the pages, so I would like to be able to just have the fact that it is implemented and has been approved, not what it is.

Mr. JOHNSON. I think that one of the members of NASA might very well discuss this with the secretary of the Council, who is stationed in their offices, and this might be done, although I couldn't say.

Mr. ROTHROCK. We are making a note of it, and will look into it and check into that.

Mr. FULTON. Thank you, Mr. Rothrock.

May I finish with this?

On the complaints as to the program, my complaints are, generally, coming from the western Pennsylvania industrial area. That includes probably eastern Ohio and northern West Virginia, and of course Pennsylvania, that the people who are engaged in allied lines that have not yet been in the space program are not being given the opportunity to bid on some of these things like the contract that was just executed, I guess yesterday or the day before or Friday, on the carriage of rockets.

Before this committee several times I have not only said that there were other people interested but suggested that there be certain companies, which I deleted from the record because I don't want those particular ones identified, which should be approached for business.

But I am very much interested in the broad-based approach to this space program, and I want everybody to have an opportunity to bid, not just the people in my area, and it seems too much that the decisions are made and there is so much subcontracting done through people they have previously dealt with, so that it is very hard for outside companies to cut into the chain of subcontracting and production.

Now, if you people in your ARPA will give a thought to that and see what can be done to bring into this program some of these people who feel that they are thoroughly competent but somehow just can't get the way to bid on things that they feel are allied to a field that they are already working in.

Now, it might be, for example, general transportation problems, things of that type, of rockets, would well come under maybe the

freight car industry or other structures for missiles; people who make steel oil derricks obviously would be qualified and want the business.

Mr. JOHNSON. To answer your question, we are diligently trying to uncover new resources in terms of capability. We do need the smaller contractors. We do need new blood in this stream, and we have a very good program, we think, to do this, to encourage contractors of new sources to bid on our work.

Mr. FULTON. How do you do that, may I ask, just shortly, and then I am through.

Mr. JOHNSON. Well, we circulate the information very widely. For example, in the solid propellant chemical industry that I spoke of, we solicited every chemical concern that we knew of in the country and asked for a presentation from them on what they would do to provide a breakthrough on the kinds of chemicals that would then be put on the shelf to make new propellants, and I think we solicited some 70 or 80 companies.

Mr. FULTON. Would that include oil companies, too? You mentioned chemical companies.

Mr. JOHNSON. Oil; yes.

The CHAIRMAN. Gas companies, too; you might put them in.

Mr. JOHNSON. Gas? Well, any company that had a capability in terms of developing chemicals, regardless of whether they had previously been in the propellant business or not, and we did get objections. * * *

I know some of these people have protested within Congress, but this is to the point that you are making, that we have got to get in many of these cases through sources of supply. We are doing this very definitely in this case.

Mr. FULTON. My point is that I am not interested geographically between two States; for example, the controversy that has arisen between New York and California on geographical distribution. That is not my point.

My point is, are we getting a broad enough coverage of these companies in allied fields in order to get in depth the energies of various people with new points of view aimed at this scientific research and development that we need for a breakthrough?

Mr. JOHNSON. We aren't doing well as we could. We could do a lot better.

Mr. FULTON. You are doing pretty well. So I am on your team as to that. But I simply wanted to express that many of these companies that feel that they are being left out, I think part of it comes from the fact of lack of communication from some of the companies that are in the program on more or less the prime-contractor basis. They already have their subcontractors, and they have a feeling of loyalty to that group of subcontractors, and while I think that is an estimable thing for business practices, when it comes to research and development in as serious a field as this is to our national security, of course we have got to give up some of our parochial and family loyalties in the commercial field.

So my point on that is this:

We have a broad-based program, so that anybody that can get in it will have free and fair access to it. As a matter of fact, one of the perfect examples of what I am saying is the Greek, Cristofilos, the

University of California kept being turned down on the patents he submitted, all of a sudden discovered they were using one of his, and they were infringing on his patents, and they had turned him down on it.

The CHAIRMAN. Any further questions?

Mr. FULTON. I am not through.

The CHAIRMAN. I didn't get your question there.

Mr. FULTON. It is no question. It is a comment.

I am trying to say, bring the whole field of scientific and research development in the commercial area, as well as the universities, into this subject, and don't have it exclusive on the basis that there are prime and subcontractor systems that are set up that will do the job adequately anyhow, and secondly, that we do not have a loyalty between prime and subcontractors result in an exclusion of many people who would come in as new subcontractors.

Finally, on the carriage of missiles, first, I would like to question, will you please, from the ARPA point of view, explain to me why the Jupiter missile has a 20 minute countdown simply for erection to a vertical position, using the same principle that our Paducah farmers have used for 300 years in erecting barns and not quite as efficient as our Pennsylvania barn raising.

I saw that myself at the Redstone Arsenal and complained about it, and was told that I should not interfere with the training of these crews for the 20-minute countdown.

I am now directly interfering and objecting strenuously to the method, unprotected, and using the old pole in the air and pulling a line over it.

I don't know whether they had mules or people pulling the line, but they probably had a donkey engine on it.

The second point is this:

On the transportation of these, I want to know who has been checked to put research and development on the method of erecting the missiles either above the ground, in a vertical position, or possibly at some angle or possibly putting them in mounts, and while we are on that point, may I just say that I understand the Russians in Tibet have already been experimenting with high-level or extremely high-altitude launching of large missiles, and when I brought that up to a couple of scientists here in open session, I was openly laughed at. But I knew just a little bit more about it than the particular scientists.

(The following material represents ODGM comments on questions and statements of Congressman Fulton on "Jupiter Erection and Transport, High Altitude Launch Aerojet Contract":)

The technique of the A-frame and H-frame (lightweight) erection gear used to erect the Jupiter missile launcher was originally developed for the Redstone missile to replace the large heavy crane used for this purpose. The lightweight erection gear proved to be a simple, economical device which could be dismantled and transported in a standard Army vehicle. This technique was carried over into the Jupiter program and is the erecting device which has been used by the Air Force squadrons in their training with the Jupiter missile. The erection of the missile has been performed many times very satisfactorily with the actual time required dependent upon the training status of the operating crew. An adequately trained crew can move the missile from the horizontal to the vertical position in less than 5 minutes, and inasmuch as the missile is maintained in a "readiness state" in the vertical position, the few minutes used in the erection process has no bearing on the time required to make final checks of the missile guidance, fuel the missile, orient or lay the missile, and fire it.

The location of ballistic-missile-launching sites at high altitudes does provide a given missile with some increased range or increased payload. However, there are attendant problems of logistics and operations if sites are located at extreme altitudes. A number of the ICBM sites are planned for the Rocky Mountain area.

Aerojet General was given a letter award for nine Aerojet Senior Engine "Transtainers." The "Transtainer" is merely a "container" and "handling harness" which permits handling and shipping of the large Aerojet Senior solid grain to firing site and also maintains it at a controlled temperature of 70° F. to 90° F.

The NASA basic contract for 12 Aerojet "Senior" boosters is NAS–5–53 and is for about $1.1 million. The "Transtainers" are being procured by amendment to the basic contract for a total of $120,000 approximately.

Mr. FULTON. Now, the other point is this:

I would like to know what companies have been asked to bid on the contract that has just been awarded to Aerojet on the carriage of missiles, either Thursday or Friday of last week, and how many bids were received, and what the various price range was of the bids.

Then if the factor of awarding the bid was not on price, what was it on? And give the estimates of the various companies who were considered, and also the reasons for rejection of the ones that were rejected, so that I want the transportation of vehicles covered, as to the R. & D. methods that are being used to advance their progress and handling, and secondly, on the erection of missiles and establishing at cities, what is being done on the technical phase of that, and then, thirdly, on underground or underwater installations, what kind of R. & D. is being done on that.

That is all. Thank you.

The CHAIRMAN. Thank you very much for your question there.

Mr. MILLER. Mr. Chairman.

The CHAIRMAN. Mr. Miller.

Mr. MILLER. Mr. Johnson, I was interested in your statement about getting optimum development. I think you made a very fine comparison when you said we wanted to examine the number of cars in the family and make sure that two would do what the family wanted four or five to do. I think that is very sound. But in making this examination, are we going to one car when we actually need two to do the job. Are we leaning too far over backward at the present time in this field?

Mr. JOHNSON. I don't think so. I think that one of the problems that has plagued us in the military area is having multiplicity of models of capabilities and the difficult problem of choosing, then.

Mr. MILLER. I think you missed my point. You named this in connection with the expenditure of funds. Do you remember? You were talking about how we have to keep the Government solvent, and I agree that it has to be kept solvent except when it comes to defense.

You made the very nice comparison that the family, if you listened to them, would want four or five cars, but apparently when the head of the family critically examined it, he said that maybe two cars could do the trick.

Now have we reached the point where perhaps the services do not want too much, they want the four or five cars, and you are in there to tell them the number of cars they are going to get, they are going to get two cars, but do we sometimes lean a little bit too much and say,

"Well, now we are not going to get two cars, that will be too expensive, we will only buy one car"?

Mr. JOHNSON. Well, sir, to answer your question to the best of my knowledge, I do not believe there is any evidence of this latter situation. My belief is that we do have an adequate program and that we cannot at this time or should not at this time contemplate the luxury of too many alternative approaches to do the same thing.

Mr. MILLER. I do not know, I am not a scientist, I have not the experience in erecting barns as my colleague has over here. I am not going to try to tell you how to erect missiles or how to erect barns.

Mr. FULTON. We should not look down our noses at anyone by comparison. You are smart in some fields that I am ignorant in. I just happen to like this field.

Mr. MILLER. Well, I agree I am ignorant in this field, but I have always felt that in these things maybe we do need a number of approaches to get out of the haze that surrounds us. That has always been a pretty good basis for scientific investigation; has it not?

Mr. JOHNSON. Oh, yes; multiple approaches through the R. & D. period are vital, but I was directing my comments to the hardware stage.

Mr. MILLER. Well, sometimes in the hardware stage do we not have to do these things?

Mr. JOHNSON. Sometimes we do. Most of the time we do not.

Mr. MILLER. You remember we put the automobile into the hardware stage 30 or 40 years ago, but we apparently have not gotten it perfected yet because we come out with new models every year. I do not know what is on some of them.

Mr. JOHNSON. Oh, yes; I think even our hardware programs of the military must have an R. & D. content, a very high content so that that model is improved every month.

Mr. MILLER. Can that be done then with only having the limited—going back to the concept now of money—of only one car? Would it not be better if we had a hotrod for the kid to run around in? He might develop something that would help the family out.

Mr. JOHNSON. Well, to answer your question, if you have not had a presentation of the national booster program, it ought to be presented to you because you will see in the national booster program a whole series of trucks for specific missions, and I think this would answer the question you have raised very effectively. What I meant to imply was that I think there is a point where we stop the number of models at the hardware stage for the time reasons, that we should not take on the luxury of producing every R. & D. model that the proponent happens to think is the best approach. We will then have a family I think can afford it.

Mr. MILLER. I just do not want us to be too parsimonious. We might say can this be necessary, can we justify this economically, when even in the hardware stage in a new field we cannot really go that far, and as a result we may lose time. That is only a comment, Mr. Chairman, I am through.

Mr. ANFUSO. Mr. Chairman.

The CHAIRMAN. Mr. Anfuso.

Mr. ANFUSO. Mr. Johnson, I want to congratulate you for the great service which you are performing on behalf of our country and par-

ticularly for the secrecy which was attached to those three atomic blasts. I am in a mood for making awards and I think you are entitled to an award from this country for your personal human thrust—not to speak of the million-and-a-half-pound thrust—you put into being.

Mr. JOHNSON. Thank you.

Mr. ANFUSO. When do you expect, Mr. Johnson, to get a 5,000-pound or a 50,000 payload?

Mr. JOHNSON. The 50,000-pound payload that I referred to would be in a 300-mile orbit. The 5,000-pound payload would be in a stationary orbit at 22,000 miles. The objective is to accomplish this in 1962 or early 1963.

Mr. ANFUSO. And for both of those you will need a million-and-a-half-pound booster?

Mr. JOHNSON. We will need the same booster to do both missions; yes, sir, * * *

Mr. ANFUSO. Now this whole apparatus is quite an installation; is it not?

Mr. JOHNSON. Yes; it is a 12-story building, the height of a 12-story building. On the other hand, it is a straightforward job, it is an engineering job; there is not much science involved.

Mr. ANFUSO. Mr. Johnson, what I would like to know from you is to get your thinking on how you are going to protect such a very expensive and important installation.

Mr. JOHNSON. * * *
Mr. ANFUSO. * * *
Mr. JOHNSON. * * *
Mr. ANFUSO. * * *
Mr. JOHNSON. * * *
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Mr. JOHNSON. * * *
Mr. ANFUSO. * * *
Mr. JOHNSON. * * *

Mr. ANFUSO. Thank you.

The CHAIRMAN. Mr. Johnson, may I ask you a question now? We mentioned this to you earlier. In reference to the Discoverer shots, there are so many reports we read, we read some in the press and we hear some.

What is the present status of that project as far as we have information?

Mr. JOHNSON. The Discoverer I is definitely not in orbit now. The Discoverer program, however, is proceeding pretty much on schedule. There will be the launching of Discoverer II in the several weeks ahead. The program of follow-on of one per month is still definitely on the schedule.

Now if you wish to have comment on the first announcement that Discoverer I was in orbit and then later that it was not in orbit——

The CHAIRMAN. Yes; would you clear that up?

Mr. JOHNSON. I would like to have my associate here, Mr. Godel, who follows this for me, comment on it, if that is all right.

The CHAIRMAN. You have a very able associate. I happen to know some of his work.

Mr. Godel, if you will tell us.

Mr. GODEL. Thank you, Mr. Chairman. I do not know how far back it would be the committee's pleasure to go. I will summarize very briefly that on the basis of the injection data, on the basis of 9 minutes of telemetry immediately following the launch of the Discoverer and on the basis of 41 reports from tracking equipment designed for this purpose and for general-purpose tracking of vehicles extending from the time of launch through the 4th of March, the Advanced Research Projects Agency in conjunction with the Ballistic Missile Division of the Air Force concluded that the vehicle was inescapably in orbit. Subsequent to the 4th of March we received no further communications from the vehicle at the frequency, * * * and we also undertook at Mr. Johnson's request a very careful reevaluation of all of the data received up until that time. On the basis of this evaluation completed as recently as last Monday or Tuesday, we were forced to two conclusions: One, however we compute the injection data and the original tracking data received through the 4th of March, the vehicle must—even if we assumed reasonable error in our computations—the vehicle could only have gone into orbit.

On the basis of no subsequent reports following the 4th of March, it was necessary to conclude that the vehicle was no longer in orbit. We are unable to identify what took place between the 4th of March and approximately the 15th of March, or today.

The CHAIRMAN. When do you conclude it went out of orbit?

Mr. GODEL. That is the information we cannot pin down, Mr. Chairman. I can read the most recent dispatch on this to give you the rough parameters.

The CHAIRMAN. If you will.

Mr. GODEL. * * *

We have been forced to the conclusion that it did not last 28 days. We do not know at what time or where it might have gone down. We are not absolutely certain that it is down although we have reached that conclusion.

The CHAIRMAN. Tell me, how many times do you feel that it orbited the earth before it went down?

Mr. GODEL. Well, on the basis of these computations, sir, roughly an hour and a half per pass around the earth, that is 95 minutes, it would have gone around 75 to 80 or a hundred times as a minimum.

The CHAIRMAN. And that was around from north to south?

Mr. GODEL. Generally on an 87° trajectory, yes.

The CHAIRMAN. Do you have any evidence it was varying in its orbital course?

Mr. GODEL. No, sir. There would be an effective precession——

Mr. JOHNSON. It was tumbling.

Mr. GODEL. Yes, it did tumble very badly indeed which is probably the reason why the life was shorter than we computed.

The CHAIRMAN. That is probably the reason your transmitter went out, is it not?

Mr. GODEL. Yes; although regrettably we were not up there to watch it doing that so we cannot say positively.

The CHAIRMAN. Yes; but the tumbling could have thrown out of operation the transmitter.

Mr. GODEL. That is correct. The transmitter on the vehicle was highly directional for purposes of our later programs and one can fairly hypothesize at least that much of the time it was beaming out into outer space rather than into the ground.

The CHAIRMAN. Did we not have an antitumbler in there?

Mr. GODEL. Yes, sir; we have to conclude that at least one of the four objectives of this vehicle were not achieved because as I reported to you previously, one of our objectives was to stabilize the vehicle in orbit. We have concluded that we did not succeed in doing that.

The CHAIRMAN. So we have more work to do on the antitumbler.

Mr. GODEL. Yes.

The CHAIRMAN. Questions?

Mr. SISK. I wanted to ask, Is there a specific problem with reference to this tumbling in a polar orbit as against the other type of orbit?

Mr. JOHNSON. No, sir.

Mr. GODEL. The point is that until now and to our knowledge, this applies either to the Soviets or the United States, no vehicle has been successfully stabilized with respect to itself in orbit. This represents a distinct step ahead in space activities, and this is the first vehicle in which this has been attempted.

The CHAIRMAN. And we failed on that.

Mr. GODEL. So far, yes.

The CHAIRMAN. Are there any further questions?

Mr. QUIGLEY. I have one question, Mr. Chairman.

The CHAIRMAN. Mr. Quigley.

Mr. QUIGLEY. This is left over from the last movie. Did General Medaris and Dr. Von Braun ever get an answer to the request for additional money?

Mr. JOHNSON. Yes, they have; and we had a detailed presentation made by them last week and we are now studying the detailed presentation. It was made Tuesday, I believe.

Mr. GODEL. That is right.

Mr. JOHNSON. And they have all of the funds they can use at present and this is the thing that we wanted to determine. We have allocated more money to their program and they have all of the funds that they can use at this time.

Mr. QUIGLEY. Now, did they get all of the money they asked for, the stepped-up sums?

Mr. JOHNSON. For this current period, but we have done nothing as to fiscal year 1960, of course. We don't have that money now.

Mr. MILLER. Well, give them a hotrod car as to that.

Mr. QUIGLEY. Thank you, Mr. Chairman.

The CHAIRMAN. Mr. Sisk.

Mr. SISK. I had just one further question. You were speaking of course, as to the military implications involved in the 22,000-mile orbit of this vehicle which I believe you said would weight——

Mr. JOHNSON. Up to 5,000 pounds.

Mr. SISK. And I understand the purpose of that, of course, is communications. Concurrently with your work which is being done to develop and get this thing into orbit, as I understand it, if possible, by 1963, are you concurrently working on any type of vehicle that would carry a mechanic to service this vehicle, to board it or, for example, to do the occasional servicing that will be needed and maybe this sounds silly, but I don't mean it that way because we are talking about long-range things and I am curious to know if anything is being done concurrently with this program by the military with reference to a smaller type vehicle that might propel a man to it for servicing and return him to earth.

Mr. JOHNSON. We have two approaches to this. We definitely have in the study stage a kind of program that would allow a serviceman to go up there and take care of it.

Now, actually we are a long way from planning hardware for that mission, but the intermediate stage is to recover these vehicles and one of the objectives of the Discoverer program is to find out how, and we think it is a forthright job; it is going to take a little doing to recover a satellite, when we want it and at the point we want to recover it, and then we will repair it and send it up again.

Now, this is possible. We will be doing that this year. As a matter of fact, we will be doing it next month, I hope.

Mr. SISK. That, of course, is the immediate program. This other is long range, speaking about the space stations and that sort of thing.

Mr. JOHNSON. To do this I think you have to have at least this 50,000-pound satellite in orbit with the space and the arrangements so that a vehicle can go up there and attach itself to it and a man can move into an enclosure and do the job. I think perhaps this is coming when we have the 50,000-pound satellite up there or larger.

The CHAIRMAN. And you say that will be this year?

Mr. JOHNSON. No, no. What I said as to this year was that we will have the techniques worked out and will be actually recovering satellites; in other words, on command they will reenter the earth's atmosphere. We will recover them and then we can take the material out that we want to or repair it and send it back up again. We will have that capability this year.

The CHAIRMAN. Are there any further questions?

Mr. Chenoweth.

Mr. CHENOWETH. Well, isn't our problem here, Mr. Johnson, to put first things first in this situation which you are talking about?

We are confronted with a grave military emergency and possible threat and isn't that what you are trying to do, as I get it, from your statement?

Mr. JOHNSON. Yes, sir. We are concentrating entirely on the use of this new environment for military missions that might be used against us and therefore have a defense posture to defend ourselves in this new environment in that eventuality.

Everything we are doing in this area is to accomplish this. Then we are also wanting to use this environment to make better military

systems such as communications, such as navigation, such as early warning.

This is a natural extension of science in a new area.

Mr. CHENOWETH. You are spending $15 million now just on research programs for solid propellants; is that right?

Mr. JOHNSON. That is right.

Mr. CHENOWETH. How much are you spending for other research programs?

Mr. JOHNSON. We are spending approximately $80 million on defense against ballistic missiles of any kind and all kinds, including the things I testified to before, including death rays.

Mr. CHENOWETH. That is research, $80 million, in addition to this 15.

Mr. JOHNSON. That would be basic research; yes.

Mr. CHENOWETH. What would be the total overall?

Mr. JOHNSON. Overall in fiscal year 1959 I would classify $140 to $150 million as being research.

Mr. CHENOWETH. That is this fiscal year.

Mr. JOHNSON. That is right.

Mr. CHENOWETH. The Air Force and Army and NASA are spending in addition to that?

Mr. JOHNSON. Yes.

Mr. CHENOWETH. How much would they be spending?

Mr. JOHNSON. It depends on how you define research, but I think the number that has been used is about $3 billion.

Mr. CHENOWETH. Do you know of any agency, military or civilian, that is lacking for funds now to go ahead with the necessary research programs?

Mr. JOHNSON. I think that the research effort within the Department of Defense is at a very high level. I think that it couldn't be pushed very much more without a great deal of waste.

Mr. CHENOWETH. You can't accelerate it just by appropriating more money. It has to be done wisely and by some coordinated program.

Mr. JOHNSON. It is my feeling, however, that as time goes on we could stop making more outmoded hardware and spend more of that hardware money in research.

I think that the desire to go into production with all our new ideas too quickly may be costing us a little more than is necessary.

Mr. CHENOWETH. Has your experience proven that to be the case already?

Mr. JOHNSON. Yes; I do believe that in the kind of economy we are in now, in the kind of cold war we are in, we should attempt to, within the framework of our present budget, point more in research and development and less in actual hardware production.

Mr. CHENOWETH. Well, you have seen cases now where you have developed something which is already obsolete.

Mr. JOHNSON. That is correct.

Mr. CHENOWETH. You could have better used that money for further research and development.

Mr. JOHNSON. That is right.

Mr. CHENOWETH. That is the problem that you face.

Mr. JOHNSON. Thank you.

Mr. CHENOWETH. Thank you very much.

The CHAIRMAN. Would the gentleman yield?

Mr. CHENOWETH. I am finished.

The CHAIRMAN. On that point, I saw an article too in the press sometime back that the Pentagon had some $10 billion of accumulated hardware that is outmoded that is going to be offered for sale this year. Is some of that of the character that you refer to?

Mr. JOHNSON. Yes, sir.

The CHAIRMAN. I will agree with you there. It should be curtailed and disposed of.

Mr. Fulton.

Mr. FULTON. On the question of the satellite being in orbit, when the comment was made as to the first 9 minutes after launch and the receipt of telemetry signals, it was not stated whether those signals were continuous.

Mr. JOHNSON. Yes; it was a complete record for 9 minutes.

Mr. FULTON. Now, on the difference between that particular time and going up to March 4, was there a conspicuous blank and then a pickup in signals or were they fairly well distributed through that time interval?

Mr. JOHNSON. They were sporadic, but then we did get 41 contacts during that time.

Mr. FULTON. Well distributed.

Mr. JOHNSON. Yes.

Mr. FULTON. They just didn't cease for a period and then pick up again?

Mr. JOHNSON. Yes; they were sporadic.

Mr. FULTON. So they had enough distribution that you could pretty well say that the vehicle was then in one of your calculated orbits or one of your orbits that would be of great probability, that it had not gone out and come into orbit again or done something else; is that right?

Mr. JOHNSON. It confirmed the first 9 minutes.

Mr. FULTON. Could I have Mr. Godel answer that also?

Mr. GODEL. That is correct. It confirmed the first 9 minutes.

Mr. FULTON. Then on the total life of this particular satellite, as compared to the calculated time, I guess in 5 days it would probably go around the world 100 times and it would then have set a path of orbit that it would be repeating; is that not right?

Mr. GODEL. Yes, sir.

Mr. FULTON. So that then when you picked up the signals at these intervals thereafter, was it conforming to the orbital path that you had first calculated?

Mr. GODEL. Remarkably close, sir. The maximum errors computed out were 2 minutes as to time, which is feasible and only once on those, and within as little as a half degree of orbit that these sporadic reports confirmed the plotted trajectory.

Mr. FULTON. Had the perigee lowered perceptibly or was it pretty much at approximately the same point?

Mr. GODEL. This is difficult to answer, Mr. Fulton, since obviously the perigee had degraded, if the thing is not there now. The data are not such as to permit a precise answer to your question.

Mr. FULTON. So that if you were going to say the cause of the vehicle transferring from Kepler's laws to Newton's laws, you would

not be able to say that there was any impelling cause that would force it to have either disappeared into our atmosphere or gone off someplace else.

Mr. GODEL. Well, with a perigee of 112 miles, it would go down rather rapidly, and this is a fairly straightforward computation, but one would have to have more continuous coverage to answer your question in the affirmative.

Mr. FULTON. The point I am really making is, you have no scientific factual data to support your conclusion that it did end and go down because of the perigee depressing further, because you had no information on it?

Mr. GODEL. No, sir; we cannot define any information from say roughly 7 days to the present time, 10 days.

Mr. FULTON. But in the order of logical sequence of events, when it began to get into the gravitational field and that would take over from Kepler's second law, then you would say probably it burned out.

Mr. GODEL. Yes, sir; and I might add one further thing. We do have in operation the so-called silent satellite fence. This fence is at a very beginning state of R. & D. At the same time, and in order to insure that the most highly operational phases of this network had an opportunity to see the vehicle if it was in orbit, by the time it had precessed across the United States to permit that, it did not see it, which tends to confirm our conclusion that it was down.

The CHAIRMAN. It might be getting off on a tangent.

Mr. GODEL. It would have been difficult for it to happen. It would have been almost impossible for it to happen.

Mr. FULTON. The question comes up when you speak of tumbling as against revolving. You had antenna on this particular satellite?

Mr. GODEL. Yes.

Mr. FULTON. And you had the apertures for the experiments you wanted in the hull of this vehicle?

Mr. GODEL. This particular vehicle, no, sir; except for the horizon scanner which was intended for stabilization.

Mr. FULTON. Well, then, there would always be antenna exposed as distinguished from an aperture if you were on the tip of just a globe, I could see that there would be a reason for not receiving the signals, but what would you say was the cause, was it the failure of the telemetry equipment on the communications from the satellite going off and on; that doesn't sound very possible to me either.

Physically, it is impossible to say that is the tumbling action that caused it not to be received, so I would disagree with you thoroughly.

Mr. GODEL. May I perhaps explain, sir? As we previously announced, in later versions of this vehicle an attempt will be made to recover them. For such recovery experiments we need to have a very precise radio signal, that is to say, a highly directional radio signal more or less looking up the barrel from the recovery station to the point of the vehicle.

For this reason we placed a very highly directional antenna on the vehicle. This transmits an electrical signal on the frequency selected only across a very narrow beam. If then the vehicle is stabilized, it will be constantly pointing down. If the vehicle is not stabilized, it will be a great portion of its time pointing straight up into space and we won't hear it.

Mr. FULTON. Then why did you send the vehicle up when you probably felt that the stabilizing equipment wouldn't work?

Mr. GODEL. This is an R. & D. program, and we are eternal optimists.

Mr. FULTON. What kind of stabilizing experiments had you done? To me it would sound pretty easy to stabilize it. Stabilizing is one of the easiest things to do.

Mr. GODEL. That is not correct.

Mr. JOHNSON. Mr. Congressman, nobody has done it yet, including the Russians.

Mr. SISK. Will the gentleman yield there?

I wanted to say in answer to my question a while ago there hasn't been a case of one ever being stabilized, and they have been working on it so that apparently was one of the big problems. That was the point of my question.

Mr. FULTON. Well, I know some people working on stabilizing equipment and I didn't want them blamed for it.

Mr. GODEL. We don't blame anybody.

Mr. FULTON. * * *

Mr. CHENOWETH. * * *

Mr. FULTON. * * *

Mr. CHENOWETH. * * *

Mr. FULTON. * * * Now, may I finish with this?

Actually I got to thinking on the Scout solid propellant booster, you people lost that in ARPA; didn't you? It went over to NASA. Are you doing that or is NASA doing that?

Mr. JOHNSON. No; this has always been a NASA project.

Mr. FULTON. Then I will have to ask NASA for that contract of March 19, for the booster rockets, the first-stage Scout solid propellant rocket, and the thing I wondered about is the shipping contract being controlled. I want to hear about that. That is all. Thank you. I think you are both doing a good job.

The CHAIRMAN. Mr. Johnson, I think that is about all of the questions; I want to ask you this though: You do keep your projects, your R. & D. projects, entirely separate from any other defense business?

Mr. JOHNSON. ARPA is only in R. & D. work.

The CHAIRMAN. The reason I ask is this committee, of course, is set up for science and astronautics and specifically under one paragraph of the jurisdiction of the committee we have R. & D., that is research and development, and I think it is under the NASA Act, too. We pretty well cover all of the work of research and development, and we are going to ask you as a committee to keep us informed on your R. & D. projects there in the future.

Of course, this year we got started late as a new committee and we were not prepared to say whether we should have jurisdiction of the legislation covering it.

In the future that undoubtedly will be the situation. This committe will have jurisdiction of R. & D.

Mr. FULTON. May I agree with the chairman on the record on that point and further add that under subparagraph (f) of House Resolution 580 last year, that this committee is given specific jurisdiction of the control of outer space so that on anything to do with the control or

the power to control by military vehicles or for peacetime purposes, that is right here in this committee's jurisdiction where it rests.

The CHAIRMAN. So at any rate I don't think we are going to have any trouble with Mr. Johnson there. He is very cooperative and he has been with this committee, and I think he and his organization are doing an excellent job and it is a pleasure to work with him.

Mr. JOHNSON. Thank you.

The CHAIRMAN. Now, Mr. Moeller, you have a question.

Mr. MOELLER. Yes. Mr. Johnson, we know you are in research and possibly you wouldn't want to comment on this, but since we are in closed session I would like to comment on a paragraph taken from Aviation Week, February 23 issue, written by a Robert Hotz. It is a rather blistering attack because of the missile gap. This is what he says:

> In the face of these officially admitted and well-documented facts, it is difficult to comprehend why the only ICBM production line now operating in this country is operated at hardly more than 40 percent of its current tooling and plant capacity. We have listened to all of the arguments against increasing Atlas production to its current capability to make the only attempt now feasible to cut the Soviet missile superiority to a less dangerous margin in the next 3 to 5 years. None of them really holds water in the face of these facts.

Now, is this true or is this fellow just writing something out of his hat?

Mr. JOHNSON. * * *
Mr. MOELLER. * * *
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Mr. MOELLER. * * *
Mr. JOHNSON. * * *

Mr. SISK. Mr. Chairman, off the record.

(Discussion off the record.)

The CHAIRMAN. Thank you very much, Mr. Johnson, for you gentlemen coming here.

The meeting will adjourn.

(Whereupon, at 1 p.m., the committee was adjourned.)

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